Plant Sociology 61(2) 2024, 21–40 | DOI 10.3897/pls2024612/02 Topical Collection

PENSOFT. Italian Society of Vegetation Science (SISV)

New bryological data from relict mires in the Gran Sasso-Laga National Park (Central Apennines) and their interpretation according to the EUNIS classification and Habitats Directive*

Romeo Di Pietro[1,7], Safiya Praleskouskaya[2], Michele Aleffi[3], Francesco Di Pietro[4], Adriano Di Pietro[4], Giancarlo Tondi[5], Paola Fortini[6,7]

1 *Department of Planning, Design and Architecture Technology, Sapienza University of Rome, Rome, Italy*
2 *Department of Chemistry, Biology and Biotechnologies, University of Perugia, Perugia, Italy*
3 *Via Roma 188, Macerata, Italy*
4 *Faculty of Mathematics, Physics and Natural Sciences, Sapienza University of Rome, Rome, Italy*
5 *Via F. D'Ovidio 89, Rome, Italy*
6 *Department of Bioscience and Territory, University of Molise, via Hertz s.n.c Pesche (IS), Italy*
7 *NBFC, National Biodiversity Future Center, Palermo, Italy*

Corresponding author: Romeo Di Pietro (romeo.dipietro@uniroma1.it)

Academic editor: Silvia Poponessi ♦ **Received** 14 April 2024 ♦ **Accepted** 15 July 2024 ♦ **Published** 22 August 2024

Abstract

During a phytosociological field-work campaign aimed at studying some relict *Scheuchzerio-Caricetea* boreal mires of the montane and subalpine belts of the Laga Mountains, the highest and largest siliceous massif of the Apennine range, several bryophyte taxa of particular biogeographic interest were collected. Among these taxa, *Schljakovia kunzeana* and *Ptychostomum cernuum* were found to be new records for the whole Apennine range while *Hamatocaulis vernicosus* (taxon included in annex II of Habitats Directive) and *Scorpidium cossonii* as new for the Central-Southern Apennines. Two further species, *Bryum canariense*, *Plagiomnium cuspidatum*, were found to be confirmations of old records for the Central Apennines dating back to the early 1900s. At the national and regional level, nine, out of the forty-four bryophyte taxa identified in this study, were found to be new for the Lazio administrative Region, and one taxon as new for the Abruzzo Region. The majority of these new records belong to the boreal chorotype, the Laga Mountains being one of the most important conservation sites for the relict circumboreal and arctic-alpine flora in the whole Mediterranean area. According to both the EUNIS Habitat classification and the EU Habitats Directive Annex I, several, out of the 44 bryophytes identified in this study, act as diagnostic species for European Community Habitats. Nevertheless, a complete correspondence between bryophyte taxon and habitat type was not found upon comparing these two environmental policy systems.

Keywords

Biogeography, Boreal Flora, Cryptogams, EUNIS classification, Habitats Directive, High-altitude fens, Liverworts, Mediterranean mires, Mosses, Nature Conservation, Phytosociology

* Topical Collection: "Conservation and biodiversity of bryophytes in the ecosystems, and community variability".

Copyright *Romeo Di Pietro et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

The Apennines are a southern European mountain range which can be considered a deep extension of the European continent within the central Mediterranean Sea. They can be divided into three large sub-units (Northern, Central and Southern Apennines). The Northern Apennines are the northernmost sub-unit and the lowest in altitude (the highest peak, M. Cimone is 2165 m a.s.l.). However, the Northern Apennines geographical contiguity with the Western Alps and the wide occurrence of siliceous flyschoid substrates makes this sub-unit much more similar to the Alps than to the rest of the Apennines, both in floristic and biogeographical terms (Foggi 1990; Tomaselli and Agostini 1994; Di Pietro et al. 2017). These similarities are evidenced by the fact that many species typical of the boreal forests and the heathlands of the Alps and northern Europe, such as *Picea abies* (L.) H.Karst., *Pinus sylvestris* L., *Rhododendron ferrugineum* L., *Empetrum hermafroditum* Hagerup, *Vaccinium vitis-idaea* L. establish their southernmost limit precisely in the Northern Apennines. On the other hand, the Southern Apennines, despite being a little bit higher in altitude than the Northern Apennines (M. Dolcedorme on the Pollino massif reaches 2235 m a.s.l.), are located very far to the South, so they are significantly more influenced by the Mediterranean climate. Due to their geographical position (centre of the Mediterranean Sea), the Southern Apennines were only marginally affected by the glaciations and this has led to a scarce occurrence of boreal and arctic-alpine species and communities in this area, whereas the biogeographical similarities with the western sector of the Balkans are much higher (Tomaselli et al. 2003; Di Pietro 2010). The Central Apennines represent by far the highest altitudinal sector of the whole Apennine range with numerous massifs exceeding 2400 m a.s.l., such as Gran Sasso, Majella, Sibillini, Laga and Velino-Sirente, with some peaks belonging to Gran Sasso and Majella ranges greatly exceeding this altitude (e.g. M. Corno Grande 2910 m a.s.l., M. Amaro 2786 m a.s.l.). The significant influence that the Quaternary climatic upheavals had on the vegetation history of the Italian Peninsula (Follieri et al. 1988; Magri 2008), together with the rise in temperatures that occurred since the end of the last glaciation, led numerous arctic-alpine or circumboreal communities (currently classified as *Armerio-Salicetum herbaceae*, *Leontopodio-Elynetum myosuroidis*, *Caricetum kitaibelianae-rupestris*, *Galio-Silenetum acaulis*, *Achilleo-Saxifragetum aizoidis*) to find refuge within the upper altitudinal belts of the highest mountains of the Central Apennines (Biondi et al. 1999: 2000; Blasi et al. 2003; Blasi et al. 2005; Chytrý et al. 2015).

The Laga Mountains represent the siliceous sub-unit of the Gran Sasso-Monti della Laga National Park (Fig. 1). Thanks to their pelithic-arenaceous substrates, capable of a high hydric retention, the Laga Mountains host a high number of microthermic meso-hygrophilous environments, such as mires, peat bogs or swamps that are absent or significantly much rarer in the adjacent Gran Sasso range, as well as in the other high altitude limestone massifs of the Central Apennines (e.g. Sibillini Mountains, M. Terminillo and M. Velino).

Over the last two decades there have been numerous floristic and vegetational studies which have expanded the floristic and phytosociological knowledge of the Laga Mountains, especially with regards to the boreal vascular plant species and communities (see Pedrotti and Cortini Pedrotti 1978; Lattanzi et al. 1999; Tondi 2000; Di Pietro et al. 2001; Blasi et al. 2003; Tondi et al. 2003; Di Pietro 2007; Di Pietro et al. 2007; Di Pietro et al. 2008; Conti and Tinti 2008; Conti and Bartolucci 2016; Di Pietro et al. 2016; Bartolucci et al. 2022). These studies contributed significantly to the updating of the National and European syntaxonomic frameworks and vascular plant checklists (see Biondi et al. 2014; Mucina et al. 2016; Bartolucci

Figure 1. The north-western side of the Laga Mountains, the highest siliceous massif with of the whole Apennine range. In the background, M. Pizzo di Sevo (2419 m a.s.l.) on the left, and M. Cima Lepri (2445 m a.s.l.) in the center, in the Amatrice (Rieti) municipality (Photo R. Di Pietro).

et al. 2018). Instead, the studies on the cryptogamic flora have undergone a sharp decrease since the end of the last millennium. For this reason, as part of a phytosociological survey campaign aimed at investigating the never previously unstudied *Caricion davallianae* grasslands of the Laga Mountains, the bryophyte component was also detected. In this paper, we will present the results concerning the bryophyte flora.

Study area

The Laga Mountains are a 24 km long ridge with four peaks exceeding 2400 m a.s.l., which lies at the boundary between Lazio, Abruzzo and Marche regions, in the central Italy, and are the highest and largest siliceous massif of the whole Apennine range (Fig. 1). These mountains are characterized by a torbiditic succession of Messinian age known as "Laga Flysch" mainly composed of pelithic-arenaceous substrates (Fig. 2). The low permeability degree which characterizes the succession of sandstones and clays limits the percolation of rainfall waters and enables their superficial streaming out (Tondi and Plini 1995). Accordingly, the Laga Mountains are rich of springs and perennial streams even at high altitude where the accelerated erosion of the clayey-sandy substrates leads to the occurrence of deep and narrow valleys called "fossi" which characterize the whole subalpine and upper montane belts (Fig. 2d). In these areas, a high number of microthermic meso-hygrophilous environments, such as mires, peat bogs or swamps occurs. Within the stream banks of the deep N-facing valleys (Fosso della Pacina, Fosso Pelone, Cima della Laghetta), we identified high-altitude hygrophilous communities with abundant occur-

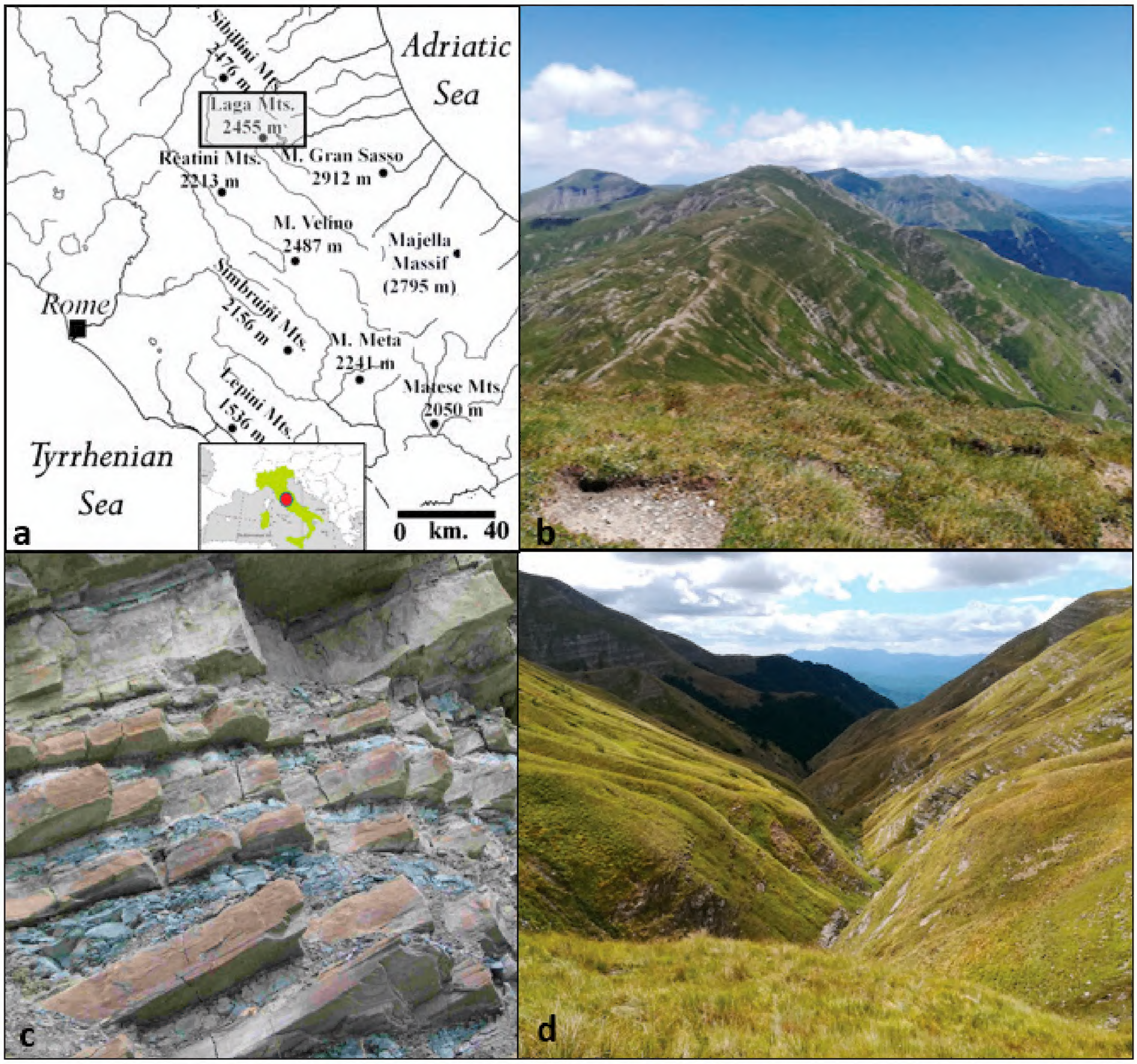

Figure 2. a) Geographical position of the Laga Mountains in the context of the Central Apennines range. **b)** Alignment of the main peaks of the Laga Mountains following a N-S direction, viewed from the top of Mount Pizzo di Sevo (2419 m a.s.l.): M. Cima Lepri (2445 m a.s.l.), M. Pizzo di Moscio (2411 m a.s.l.), M. Gorzano (2455 m a.s.l.) and M. Cima della Laghetta (2369 m a.s.l.). **c**) Typical pelithic-arenaceous substrates of the Laga Mountains Flysch; **d**) North-facing deep valley known as "Fosso Pelone" (one of the sampled areas) (Photo R. Di Pietro and F. Di Pietro).

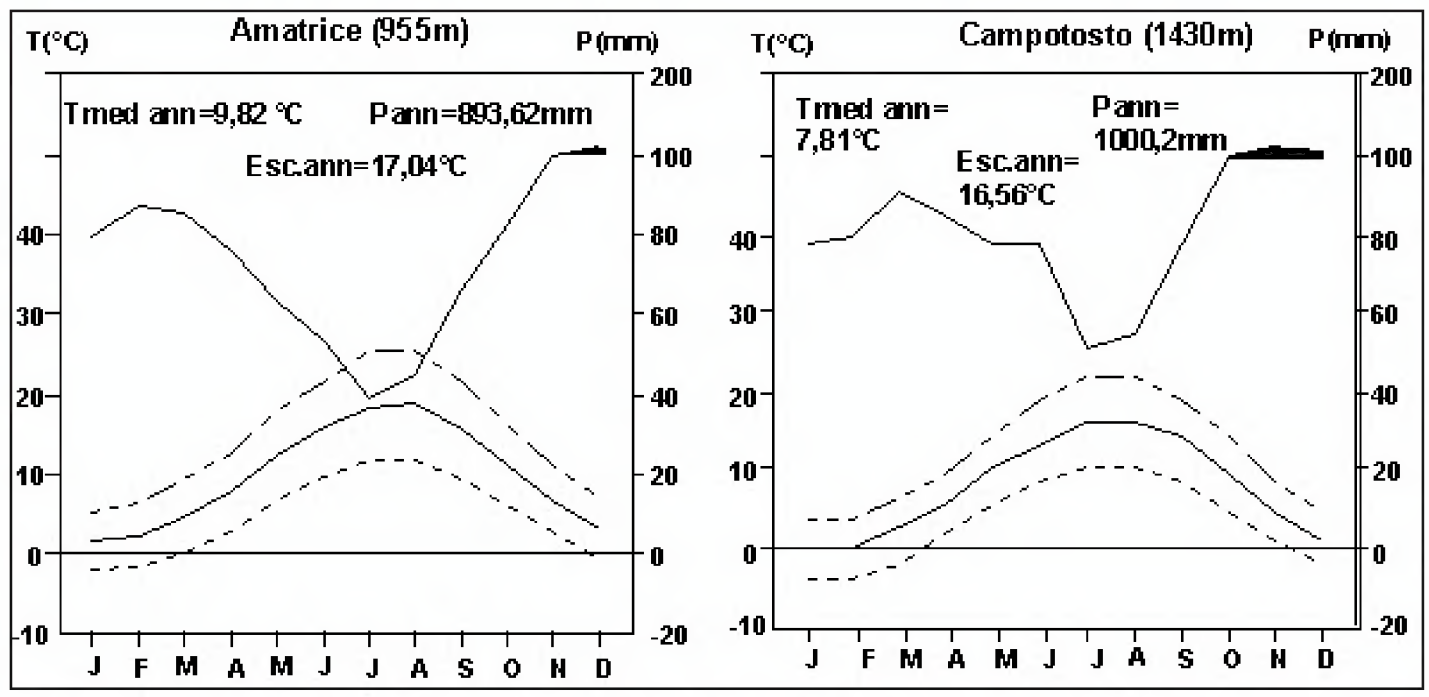

Figure 3. Ombrothermic diagram of the municipalities of Amatrice (Lazio) and Campotosto (Abruzzo). Abbreviations: T med ann = Mean Annual Temperature; P. ann = Mean annual precipitation; Esc. ann = Temperature annual range (difference between the temperature of the hottest and coldest months).

rence of bryophytes, characterized by the dominance of small sedges (e.g. *Carex frigida* All., *C. flacca* Schreber subsp. *flacca*, *C. davalliana* Sm.) and rushes (*Juncus articulatus* L. subsp. *articulatus*, *J. alpinoarticulatus* Chaix subsp. *alpinoarticulatus*, *J. arcticus* Willd.). At lower altitude (Fosso Cerruglia, Castellano river), more structured mires characterized by *Menyanthes trifoliata* L., *Succisa pratensis* Moench. and several medium-size sedges (*Carex acuta* L., *C. panicea* L., *C. pallescens* L.) and rushes (e.g. *Juncus inflexus* L., *J. conglomeratus* L.) were found.

From a bioclimatic point of view, the study area belongs to the Temperate region and to the cold axeric subregion. Mean annual temperature is 5.5°C and the mean temperature of the coldest month is –4°C. Rainfall exceeds 1600 mm/yr and in the period between November and May assume snowy features; frost occurs for more than one month yearly (Blasi 1994). These climatic features are significantly different from those observable in the ombrothermic diagrams of the only two climatic stations for which a series of precipitation and temperature data spanning several decades were available (i.e. Amatrice – Rieti and Campotosto – L'Aquila) and which are located (especially Amatrice) at altitudes much lower than that of the sampled areas (Fig. 3).

Bryological background

The first mention of bryophytes for the Laga Mountains dates back to the mid-1800s by Rabenhorst (1849–50) who reports the occurrence of *Fontinalis antipyretica* Hedw. along the course of the Castellano stream. Subsequently, Arcangeli (1887) mentions *Bryum schleicheri* Lam. et DC. [= *Ptychostomum schleicheri* (DC.) J.R.Spence ex D.Bell & Holyoak var. *schleicheri*] for Mount Pizzo di Sevo. Other sporadic reports were provided in the first half of the 1900s by Zodda (1910, 1947), Bottini (1913) and Barsali (1914) for various localities of the Laga Mountains. More recent are the contributions by Orsomando (1972), who cites 11 bryophyte (10 mosses and 1 liverwort) from the north-eastern sector of the Laga Mountains (site of "Valle della Corte" in the Marche administrative Region) and by Pedrotti (1982, 1985) who reports *Polytrichum norvegicum* Hedw. (= *Polytrichastrum sexangulare* (Brid.) G.L.Sm.) for the western side of Mount Pizzo di Sevo in the Lazio administrative Region. More substancial contributions regarding the bryophytes of the Laga Mountains are those carried out by Aleffi and Cortini Pedrotti (1991) and by Mastracci and Düll (1991) both based on the field excursion carried out in various localities of the Abruzzo administrative region during the Bryology International Congress held in L'Aquila in July 1991. In particular, Aleffi and Cortini Pedrotti added 3 liverworts and 24 mosses (from various sites of the Laga Mountains), while Mastracci and Düll listed a total of 24 liverworts and 85 mosses, all coming from the site of Bosco Martese, the widest *Abies alba-Fagus sylvatica* forest of the Central Apennines. A truly systematic study on the bryophyte flora of the Laga Mountains was carried out by Aleffi et al. (1997) where a total of 269 taxa of bryophytes were reported (75 liverworts and 194 mosses). Further sporadic contributions were those related to a general research on the vegetation of the upper montane and subalpine belts of the Laga Mountains, which led to the discovery of *Plagiomnium ellipticum* (Brid.) T.J.Kop., *Palustriella commutata* (Hedw.) Ochyra var. *sulcata* (Lindb.) Ochyra [= *P. falcata* (Brid.) Hedenäs] (Fig. 4) and *Marchantia polymorpha* L. subsp. *montivagans* (Privitera et al. 2006), and subsequently of *Myurella sibirica* (Müll.Hal.) Reimers, *Dicranella cerviculata* (Hedw.) Schimp., *Dicranum flexicaule* Brid., *D. polysetum* Sw. ex Anon. and *Pseudoleskea patens* (Lindb.) Kindb. (= *Lescuraea patens* Lindb.) (Puglisi et al. 2011). All these records confirmed the important role played by the Laga Mountains as a preferential refuge site for arctic-alpine taxa in the southern Europe. According to Aleffi et al. (1997), the bryophyte flora of the Laga mountains is characterized by a prevalence of the Temperate element, both among mosses (35.58%) and liverworts (29.34%). The contribution

of the Boreal element is significant, especially among the liverworts (28%), while the Subarctic-Subalpine element is relevant among both liverworts (12%) and mosses (9.28%). The high incidence of the Subarctic-Subalpine and Boreal elements is largely related to the high average altitude of the Laga Mountains, but also to the dense network of runoff water (even at high altitudes) which allows the survival of many microthermic species by counteracting the drop in summer rainfall due to the influence of the Mediterranean climate.

Material and methods

Bryophyte specimens were collected during a phytosociological sampling campaign aimed to describe some types of wet meadows rich in boreal species occurring within the upper montane belt of the Laga Mountains and referable to *Scheuchzerio palustris-Caricetea fuscae* and presumably belonging to Habitat 7210 or 7220 of the Directive 92/43/ECC (see Discussion paragraph). The phytosociological sampling was carried out following the phytosociological approach (Braun-Blanquet 1964).

For the identification of the bryological component reference was made to Cortini Pedrotti (2001, 2005); nomenclature follows Hodgetts et al. (2020). Chorotypes were referred to Düll (1983, 1984, 1985). Species distribution in the Italian regions refers to Aleffi et al. (2023).

Regarding the conservation status of the species collected, reference was made to Puglisi et al. (2023) for liverworts and hornworts and to Puglisi et al. (2024) for mosses, on the basis of the criteria established by IUCN (2012a, 2012b, 2022). These assessments were compared with the ones proposed at European level by Hodgetts et al. (2019) and Hodgetts and Lockhart (2020) which were based on the IUCN Red Listing guidelines (IUCN 2014).

The bryophyte specimens were grouped according to the collection site. New records for the Apennines were marked with (§) while the new regional records were marked with an asterisk (*).

Voucher specimens are deposited in the Herbarium Flaminio (HFLA; Thiers, 2022 [continuously updated]).

For each site of collection of bryophytes, a phytosociological relevé describing the coenological features of the vascular plant communities was also carried out.

Vascular plants specimens were identified according to Pignatti et al. (2017–2019) whereas nomenclature follows Bartolucci et al. (2018). For the nomenclature of syntaxa and their classification at the class rank reference was made to Mucina et al. (2016). The complete names of the syntaxa are reported in Appendix 1.

Some bryophyte taxa, out of the 44 identified, are currently considered to be diagnostic for European habitats reported both in the EUNIS classification (Davies et al. 2004; Moss 2008), and in the Annex I of the 92/43/EEC Habitats Directive (European Commission 2013). As far as the EUNIS classification is concerned, we made reference to the Habitat factsheets deriving from the expert system EUNIS-ESy (Chytrý et al. 2020) where habitats description, distribution and combination of diagnostic and constant species was established according to the classification of vegetation plots taken from the European Vegetation Archive EVA (Chytrý et al. 2016).

Results

Sixty phytosociological relevé were performed between 2021 and 2022 to describe and syntaxonomically classify the stream bank microthermic rush-sedge meadows of the N-facing slopes of the subalpine and upper montane belts of the Laga Mountains.

An analysis of the bryological component collected during the field sampling led to the identification of several taxa of biogeographical importance. Some of these taxa are considered diagnostic for EU. Habitats which are currently reported for the Central and Southern Apennines by the official documents of 92/43/EEC Directive but which knowledge (and geographical mapping) is essentially based on "virtual" information (no published data). Among the various taxa identified, we found several rare bryophytes exhibiting here their southernmost limit of distribution and acting as new records for the regional bryophyte flora of Italy. Four bryophyte taxa were never reported for the Central Apennines. These are *Schljakovia kunzeana* (Huebener) Konstant. & Vilnet and *Ptychostomum cernuum* (Hedw.) Hornsch. (new for the whole Apennines), *Hamatocaulis vernicosus* (Mitt.) Hedenäs, and *Scorpidium cossonii* (Schimp.) Hedenäs (new for the Central-Southern Apennines).

From a regional floristic point of view, nine species of bryophytes (i.e. *Flexitrichum gracile* (Mitt.) Ignatov & Fedosov, *Hamatocaulis vernicosus* (Mitt.) Hedenäs, *Pellia neesiana* (Gottsche) Limpr., *Philonotis seriata* Mitt., *Ptychostomum cernuum* (Hedw.) Hornsch., *Riccardia multifida* (L.) Gray subsp. *multifida*, *Sarmentypnum exannulatum* (Schimp.) Hedenäs, *Schljakovia kunzeana* (Huebener) Konstant. & Vilnet, *Scorpidium cossonii* (Schimp.) Hedenäs) were found to be new for the Lazio administrative Region and one species, *Philonotis rigida* Brid., for the Abruzzo Region. Two further species (*Bryum canariense* Brid. and *Plagiomnium cuspidatum* (Hedw.) T.J.Kop.) were confirmed after old records dating back to the early 1900s.

In the chorological spectrum (Fig. 5), the Boreal chorological element (which is divided into the four chorotypes, boreal, montane-boreal, dealp-boreal and sub-boreal) appears to be dominant, comprising about 50% of the species identified. Also relevant is the contribution of the Temperate element, which sums up approximately 36% of individuals, while the Mediterranean-Oceanic and Submediterranean-montane element exhibit very low percentages.

As far as the conservation status of the species is concerned, the assessments reported in Puglisi et al. (2023, 2024) for liverworts, hornworts and mosses, differ in part

Figure 4. Boreal moss *Palustriella falcata* (Brid.) Hedenäs dominant in the *Carex frigida* All. and *Pinguicula vulgaris* L. mire communities of Fosso della Pacina site in the N-facing valleys of the upper montane belt of the Laga mountains (1700 m a.s.l.).

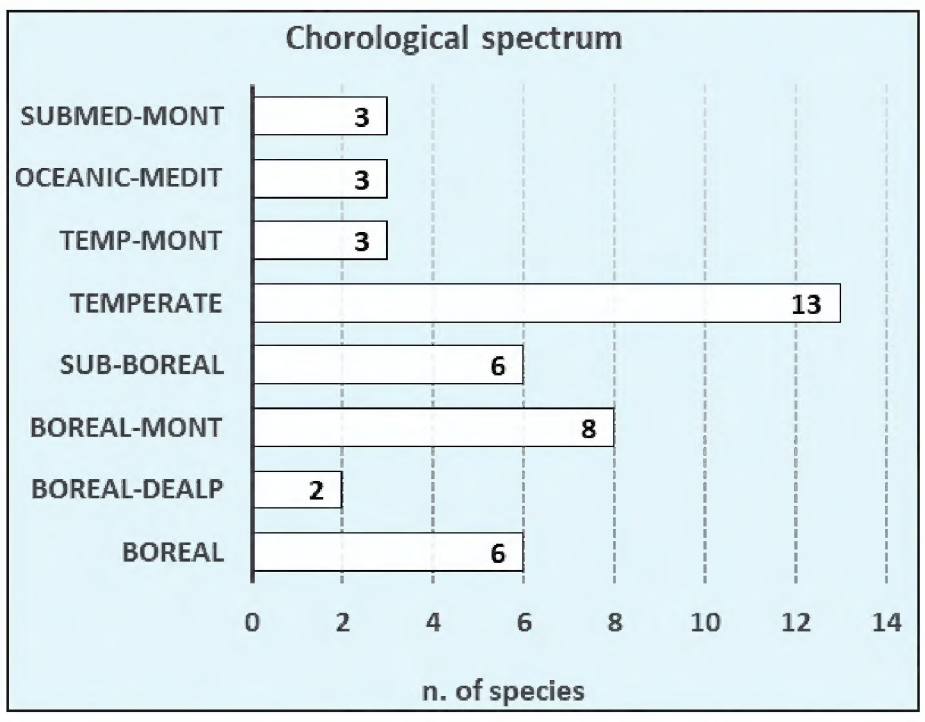

Figure 5. Chorological spectrum calculated on the forty-four bryophyte species identified growing in the fen and mire vegetation of the Laga Mountains. For the chorological meaning of some of the categories here listed see also Cortini Pedrotti et al. (1991).

from what was previously reported in Hodgetts and Lockhart (2020) both at European and Country level. In fact, *Ptychostomum cernuum* (Hedw.) Hornsch. and *Schljakovia kunzeana* (Huebener) Konstant. & Vilnet are the only two species we collected which are classified as EN-endangered in Puglisi et al. (2023, 2024), whereas *S. kunzeana* was previously classified as CR-critically endangered in Hodgetts and Lockhart (2020). *Dicranella rufescens* (Dicks.) Schimp. and *Philonotis rigida* Brid. are both considered NT-near threatned in Puglisi et al. (2024), whereas they were respectively classified as LC-least concern and VU-vulnerable in Hodgetts and Lockhart (2020). *Scorpidium cossonii* was considered EN-endangered only in Hodgetts and Lockhart (2020). Ten species (i.e. *Aneura pinguis* (L.) Dumort., *Conocephalum conicum* (L.) Dumort. *Marchantia polymorpha* L. subsp. *polymorpha*, *Marchantia quadrata* Scop., *Mesoptychia badensis* (Gottsche ex Rabenh.) L.Söderstr. & Váňa, *Mesoptychia bantriensis* (Hook.) L.Söderstr. & Váňa, *Pedinophyllum interruptum* (Nees) Kaal., *Pellia epiphylla* (L.) Corda, *Pellia neesiana* (Gottsche) Limpr., *Riccardia multifida* (L.) Gray) were considered as NT in Hodgetts and Lockhart (2020), whereas they have been classified LC-Least Concern in Puglisi et al. (2023; 2024). Finally, *Conocephalum salebrosum* Szweyk., Buczk. & Odrzyk was considered as DD-Data deficient in Hodgetts and Lockhart (2020), and LC in Puglisi et al. (2023).

The bryophyte taxa currently considered diagnostic for the European habitats according both to the EUNIS classification system and the 92/43/EEC Directive Interpretation Manual are reported in Tables 1, 2.

It emerged that there is not an exclusive relationship between bryophyte species and Habitat type, but the same species can be classified as diagnostic in different habitats (e.g. *Campylium stellatum* is considered diagnostic for Habitats Q41, Q42, Q44, Q45, Q46 in the EUNIS classification as well as *Scorpidium cossonii* is considered diagnostic for Habitats 7220; 7230; 7240; 7310 in the Interpretation Manual of the Habitats Directive).

Table 1. Distribution of bryophyte diagnostic species in the different habitats according to the EUNIS habitat factsheets (Chytrý et al. 2020). The correspondence between EUNIS code and Habitats Directive Annex 1 code is also reported. The symbol "x" indicates that no match was found in Annex I of the Habitats Directive for some EUNIS codes reported in the table.

Eunis code	Factsheet code	92/43/EEC Annex 1	Eunis Habitat Factsheet diagnostic species	Eunis Habitat Factsheet constant species
B1.6a	N1A	2160	*Brachythecium rutabulum*	*Brachythecium rutabulum*
B1.7a	N1D	2180	*Brachythecium rutabulum*	*Brachythecium rutabulum*
B1.8a	N1H	2190	.	*Calliergonella cuspidata*
D1.1	Q11	7110	.	*Aulacomnium palustre*
D2.1	Q21	7140	.	*Aulacomnium palustre*
D2.2a	Q22	7140	.	*Aulacomnium palustre*
D2.2b	Q23	6160	*Philonotis seriata*, *Ptychostomum pseudotriquetrum*, *Sarmentypnum exannulatum*	*Aneura pinguis*, *Aulacomnium palustre*, *Campylium stellatum*, *Palustriella commutata*, *Philonotis seriata*, *Ptychostomum pseudotriquetrum*, *Sarmentypnum exannulatum*
D2.2c	Q24	7130	*Sarmentypnum exannulatum*	*Aulacomnium palustre*, *Calliergonella cuspidata*, *Ptychostomum pseudotriquetrum*, *Sarmentypnum exannulatum.*
D4.1a	Q41	7230	*Campylium stellatum*, *Palustriella commutata*, *Philonotis calcarea*, *Ptychostomum pseudotriquetrum*	*Aneura pinguis*, *Calliergonella cuspidata*, *Campylium stellatum*, *Palustriella commutata*, *Philonotis calcarea*, *Ptychostomum pseudotriquetrum*
D4.1	Q42	7230	*Aneura pinguis*, *Aulacomnium palustre*, *Campylium stellatum*, *Hamatocaulis vernicosus*, *Ptychostomum pseudotriquetrum*	*Aneura pinguis*, *Aulacomnium palustre*, *Calliergonella cuspidata*, *Campylium stellatum*, *Hamatocaulis vernicosus*, *Ptychostomum pseudotriquetrum*
D4.1b	Q43	7210	*Aneura pinguis*, *Campylium stellatum*	*Aneura pinguis*, *Calliergonella cuspidata*, *Campylium stellatum*, *Ctenidium molluscum*, *Palustriella commutata*, *Ptychostomum pseudotriquetrum*
D4.1c	Q44	7140	.	*Aneura pinguis*, *Campylium stellatum*, *Ptychostomum pseudotriquetrum*
D4.2	Q45	7240	*Campylium stellatum*, *Palustriella commutata*, *Ptychostomum pseudotriquetrum*	*Aneura pinguis*, *Campylium stellatum*, *Palustriella commutata*, *Ptychostomum pseudotriquetrum*
D614	Q46	7230	*Campylium stellatum*, *Ptychostomum pseudotriquetrum*	*Calliergonella cuspidata*, *Campylium stellatum*, *Ptychostomum pseudotriquetrum*
E1.1d	R13	6110	.	*Tortella tortuosa*
E1.7	R1M	6230	.	*Rhytidiadelphus squarrosus*
E1.B	R1S	6130	*Brachythecium rutabulum*, *Rhytidiadelphus squarrosus*	*Brachythecium rutabulum*, *Rhytidiadelphus squarrosus*
E2.3	R23	6520	.	*Rhytidiadelphus squarrosus*
E3.4a	R35	6440	.	*Calliergonella cuspidata*
E3.4b	R37	6410	.	*Calliergonella cuspidata*, *Rhytidiadelphus squarrosus*
E4.3a	R42	6150	.	*Rhytidiadelphus squarrosus*
E4.4a	R44	6170	.	*Tortella tortuosa*
F1.1	S11	x	*Schljakovia kunzeana*	.
F1.2	S12	x	*Schljakovia kunzeana*	.
F2.4	S26	4070	.	*Tortella tortuosa*
F3.1g	S37	x	.	*Ctenidium molluscum*, *Plagiomnium undulatum*
F9.2	S92	4080	.	*Calliergonella cuspidata*
G1.2a	T12	9030	*Plagiomnium undulatum*	*Brachythecium rutabulum*, *Plagiomnium undulatum*
G1.2b	T13	91F0	.	*Brachythecium rutabulum*, *Plagiomnium undulatum*
G1.4	T15	9080	*Calliergonella cuspidata*	*Brachythecium rutabulum*, *Calliergonella cuspidata*
G1.5	T16	91D0	.	*Aulacomnium palustre*
G1.Ab	T1F	9180	.	*Ctenidium molluscum*, *Plagiomnium undulatum*
G3.1a	T31	9410	.	*Ctenidium molluscum*
G3.2	T34	9430	.	*Tortella tortuosa*
G3.4b	T36	9530	.	*Tortella tortuosa*
G3.Da	T3J	91D0	*Aulacomnium palustre*	*Aulacomnium palustre*
G3.Db	T3K	91D0	.	*Aulacomnium palustre*
H2.2	U25	8120	.	*Aulacomnium palustre*
H3.1b	U32	8220	*Dicranella rufescens*	.
H3.4	U3D	x	*Eucladium verticillatum*	*Palustriella commutata*

Table 2. Distribution of bryophyte diagnostic species in the different habitats listed in the 92/43/EEC Habitats Directive Interpretation Manual (Eur 28).

7140	*Aneura pinguis*, *Campylium stellatum*, *Scorpidium cossonii*
7160	*Philonotis calcarea*, *P. marchica*, *P. rigida*, *P. seriata*, *Plagiomnium undulatum*, *Pohlia wahlenbergii*, *Ptychostomum pseudotriquetrum*, *Sarmentypnum exannulatum*
7220	*Eucladium verticillatum*, *Hamatocaulis vernicosus*, *Philonotis calcarea*,*Scorpidium cossonii*, *Ptychostomum pseudotriquetrum*
7230	*Calliergonella cuspidata*, *Campylium stellatum*, *Ctenidium molluscum*, *Ptychostomum pseudotriquetrum*, *Scorpidium cossonii*
7240	*Scorpidium cossonii*
7310	*Sarmentypnum exannulatum*, *Scorpidium cossonii*
9050	*Brachythecium rivulare*, *Plagiomnium cuspidatum*, *Plagiomnium undulatum*

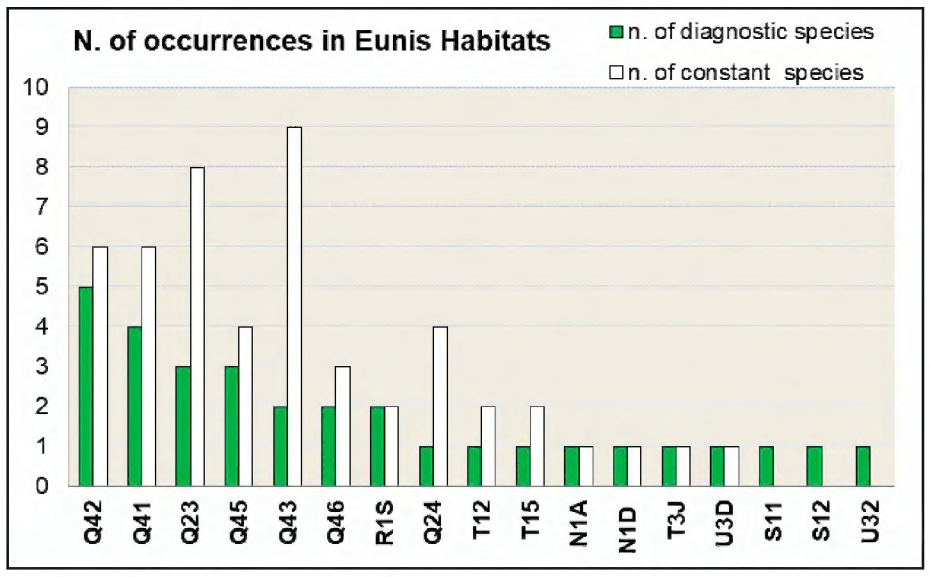

Figure 6. Number of "diagnostic" and "constant" species, among those identified in this study, in the different habitats reported in the EUNIS factsheets lists (only habitats containing diagnostic species are reported in the histogram). **Q42:** Extremely rich moss-sedge fen; **Q41:** Alkaline, calcareous, carbonate-rich small-sedge spring fen; **Q23:** Relict mire of Mediterranean mountains; **Q45:** Arctic-alpine rich fen; **Q43:** Tall-sedge base-rich fen; **Q46:** Carpathian travertine fen with halophytes; **R1S**: Heavy-metal grassland in Western and Central Europe; **Q24:** Intermediate fen and soft-water spring mire; **T12:** *Alnus glutinosa-Alnus incana* forest on riparian and mineral soils; **T15:** Broadleaved swamp forest on non-acid peat; **N1A:** Atlantic and Baltic coastal dune scrub; **N1D:** Atlantic and Baltic broad-leaved coastal dune forest; **T3J:** *Pinus* and *Larix* mire forest; **U3D:** Wet inland cliff; **S11:** Shrub tundra; **S12:** Moss and lichen tundra; **U32:** Temperate high-mountain siliceous inland cliff.

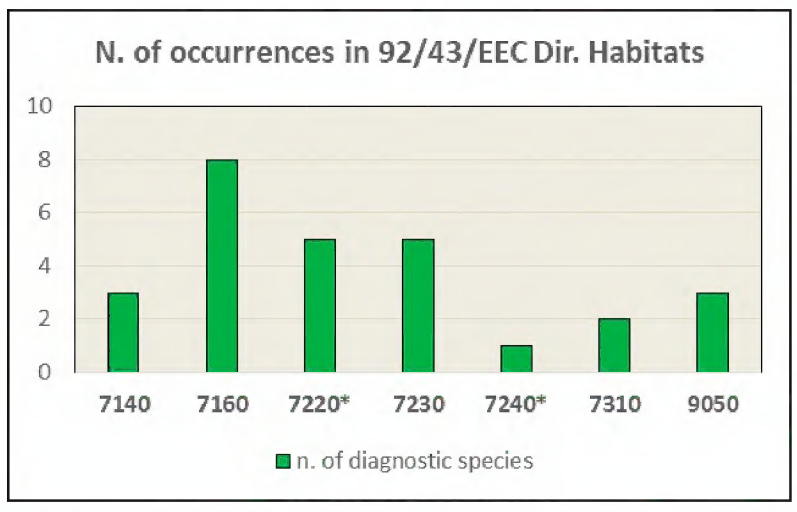

Figure 7. Number of "diagnostic" species, among those identified in this study, in the different habitats reported in the 92/43/EEC Interpretation manual (Only Habitats containing diagnostic species are reported in the histogram). **7140:** Transition mires and quaking bogs; **7160:** Fennoscandian mineral-rich springs and springfens; **7220*:** Petrifying springs with tufa formation (*Cratoneurion*); **7230:** Alkaline fens; **7240*:** Alpine pioneer formations of *Caricion bicoloris-atrofuscae*; **7310:** Boreal mires; **9050**: Fennoscandian herb-rich forests with *Picea abies*.

Twenty-three taxa were found to be classified as diagnostic species and/or constant species within 40 habitat factsheets reported by the EUNIS classification (Table 1) whereas 17 species distributed within 7 habitats were found to be diagnostic in the Habitats Directive Annex I (Table 2). The histograms displaying the distribution of the diagnostic species per Habitat type are reported in Figs 6, 7.

We report the list of bryophyte taxa gathered in each collection site. In order to provide information on the coenological features of the different sites of collections, eight phytosociological relevés (one for each site) of the related vascular plant communities are reported.

List of the collection sites (Gran Sasso-Laga National Park)

Site 1: Fosso Gorzano (central Italy, Lazio Region)
Campylium stellatum (Hedw.) Lange & C.E.O.Jensen
Cratoneuron filicinum (Hedw.) Spruce
Palustriella commutata (Hedw.) Ochyra
Philonotis calcarea (Bruch & Schimp.) Schimp.
Ptychostomum pseudotriquetrum (Hedw.) J.R.Spence & H.P.Ramsay

Vegetation type: *Eriophorum latifolium* & *Carex frigida* comm.

Phytosociological relevé. Date: 10/07/2022; **Samplers:** R. Di Pietro, S. Praleskouskaya; **Coordinates:** WGS84: 42.629331°N, 13.377575°E; **Altitude:** 1585 m a.s.l.; **Area:** 16 m^2; **Cover:** (100%); **Rockiness:** (---); **Stoniness:** (---); **Environment**: humid fen at the edge of the beech forest; **Preliminary syntaxonomic classification**: *Caricion davallianae.*

Phytosociological Sample:

Scheuchzerio-Caricetea fuscae: *Carex frigida* All. 2, *Juncus articulatus* L. 2, *Parnassia palustris* L. 2, *Pinguicula vulgaris* L. 2, *Blysmus compressus* (L.) Panz. ex Link 3, *Eriophorum latifolium* Hoppe 3, *Dactylorhiza maculata* (L.) Soó subsp. *fuchsii* (Druce) Hyl. 1, *Carex davalliana* Sm. 1, *Eleocharis quinqueflora* (Hartmann) O.Schwarz +, *Carex viridula* Michx. 1, *Juncus arcticus* Willd. 2, *Dactylorhiza incarnata* (L.) Soó +, **Molinio-Arrhenatheretea:** *Carex flacca* Schreb. 3, *Alchemilla reniformis* Buser +, *Leucanthemum ircutianum* DC. 1, *Trifolium pratense* L. +, *Prunella vulgaris* L. 2, *Trifolium repens* L. 1, **Montio-Cardaminetea:** *Saxifraga aizoides* L. +, *Alchemilla coriacea* Buser 1, **Mulgedio-Aconitetea:**

Tussilago farfara L. 2, **Nardetea strictae:** *Nardus stricta* L. +, *Brachypodium genuense* (DC.) Roem. & Schult. +, *Plantago maritima* L. subsp. *serpentina* (All.) Arcang. +, *Viola canina* L. +, **Elyno-Seslerietea:** *Lotus corniculatus* L. subsp. *alpinus* (DC.) Rothm. +, *Alchemilla nitida* Buser +, *Polygala alpestris* Rchb. subsp. *alpestris* +, **Loiseleurio-Vaccinetea:** *Juniperus communis* L. subsp. *nana* Syme 1, **Festuco-Brometea:** *Leontodon hispidus* L. 2, *Briza media* L. +, *Linum catharticum* L. +, *Trifolium montanum* L. subsp. *rupestre* (Ten.) Nyman +, **Salicetea purpureae:** *Salix caprea* L. +, *Salix purpurea* L. +, *Salix apennina* A.K.Skvortsov 1, **Carpino-Fagetea:** *Listera ovata* (L.) R.Br. +.

Site 2: Fosso della Pacina (central Italy, Lazio Region) (Fig. 8)

Apopellia endiviifolia (Dicks.) Nebel & D.Quandt
Aneura pinguis (L.) Dumort.
Campylium stellatum (Hedw.) Lange & C.E.O.Jensen
Cratoneuron filicinum (Hedw.) Spruce
**Flexitrichum gracile* (Mitt.) Ignatov & Fedosov
Marchantia quadrata Scop.
Mesoptychia badensis (Gottsche ex Rabenh.) L.Söderstr. & Váňa
Mesoptychia bantriensis (Hook.) L.Söderstr. & Váňa
Palustriella falcata (Brid.) Hedenäs
**Pellia neesiana* (Gottsche) Limpr.
Philonotis calcarea (Bruch & Schimp.) Schimp.
Ptychostomum pseudotriquetrum (Hedw.) J.R.Spence & H.P.Ramsay
**Riccardia multifida* (L.) Gray
§**Schljakovia kunzeana* (Huebener) Konstant. & Vilnet
§**Scorpidium cossonii* (Schimp.) Hedenäs

Vegetation type: *Carex frigida* and *Juncus articulatus* comm.

Phytosociological relevé. Date: 10/07/2022; **Samplers:** R. Di Pietro, S. Praleskouskaya; **Coordinates:** WGS84: 42.629153°N, 13.390942°E; **Altitude:** 1740 m a.s.l.; **Area:** 3 m^2; **Cover:** (100%); **Rockiness:** (---); **Stoniness:** (---); **Environment:** stream bank vegetation; **Preliminary syntaxonomic classification**: *Caricion davallianae*

Phytosociological Sample:

Scheuchzerio-Caricetea fuscae: *Carex frigida* All. 4, *Juncus articulatus* L. 2, *Parnassia palustris* L. 1, *Pinguicula vulgaris* L. 2, *Dactylorhiza maculata* (L.) Soó subsp. *fuchsii* (Druce) Hyl. +; **Molinio-Arrhenatheretea**: *Carex flacca* Schreb. 2, *Alchemilla reniformis* Buser +, *Leucanthemum ircutianum* DC. +, *Trifolium pratense* L. +, *Crepis aurea* (L.) Cass. subsp. *glabrescens* (Caruel) Arcang. +; **Montio-Cardaminetea:** *Saxifraga aizoides* L. 2, **Mulgedio-Aconitetea:** *Jacobaea alpina* (L.) Moench subsp. *samnitum* (Nyman) Peruzzi 2, *Pedicularis comosa* L. +, **Nardetea strictae:** *Ranunculus apenninus* (Chiov.) Pignatti +, **Elyno-Seslerietea:** *Bistorta vivipara* (L.) Delarbre 2, *Lotus corniculatus* L. subsp. *alpinus* (DC.) Rothm. +, *Alchemilla nitida* Buser +, *Gentiana verna* L. 1, *Pedicularis verticillata* L. +, **Festuco-Brometea:** *Leontodon hispidus* L. +, *Gymnadenia conopsea* (L.) R. Br. +, *Linum catharticum* L. +.

Site 3: Fosso Pelone (central Italy, Lazio Region)

Bryum canariense Brid.
Campylium stellatum (Hedw.) Lange & C.E.O.Jensen
Conocephalum salebrosum Szweyk., Buczk. & Odrzyk
Dicranella rufescens (Dicks.) Schimp.
Drepanocladus aduncus (Hedw.) Warnst.
Eucladium verticillatum (With.) Bruch & Schimp.
Gymnostomum calcareum Nees & Hornsch.
§**Hamatocaulis vernicosus* (Mitt.) Hedenäs
Palustriella commutata (Hedw.) Ochyra
Pedinophyllum interruptum (Nees) Kaal.
Pellia epiphylla (L.) Corda
Philonotis marchica (Hedw.) Brid.
**Philonotis seriata* Mitt.
Pohlia wahlenbergii (F.Weber & D.Mohr) A.L.Andrews
**Ptychostomum cernuum* (Hedw.) Hornsch.
Rhynchostegium riparioides (Hedw.) Cardot
Rhythidiadelphus squarrosus (Hedw.) Warnst.
**Sarmentypnum exannulatum* (Schimp.) Hedenäs
Tortella tortuosa (Hedw.) Limpr.

Vegetation type: *Carex frigida* and *Juncus articulatus* comm.

Phytosociological relevé. Date: 22/07/2022; **Samplers:** R. Di Pietro, F. Di Pietro, A. Di Pietro; **Coordinates:** WGS84: 42.635831°N, 13.394442°E; **Altitude:** 1850–2050 m a.s.l.; **Area:** 10 m^2; **Cover:** (100%); **Rockiness:** (---); **Stoniness:** (---); **Environment**: small fens nearby the melting-snow streams; **Preliminary syntaxonomic classification**: *Caricion davallianae*

Phytosociological Sample:

Scheuchzerio-Caricetea fuscae: *Carex frigida* All. 3, *Juncus articulatus* L. 3, *Parnassia palustris* L. 1, *Equisetum variegatum* Schleich. ex F.Weber & D.Mohr 3, *Pinguicula vulgaris* L. 3, *Juncus alpinoarticulatus* Chaix 1, *Blysmus compressus* (L.) Panz. ex Link 2, *Eriophorum latifolium* Hoppe 3, *Dactylorhiza maculata* (L.) Soó subsp. *fuchsii* (Druce) Hyl. 2, *Eleocharis quinqueflora* (Hartmann) O.Schwarz 1, *Juncus arcticus* Willd. 1, *Tofieldia calyculata* (L.) Wahlenb. 2, *Pedicularis verticillata* L. +, **Molinio-Arrhenatheretea:** *Carex flacca* Schreb. subsp. *flacca* 2, *Agrostis stolonifera* L. subsp. *stolonifera* 1, *Alchemilla reniformis* Buser 2, *Leucanthemum ircutianum* DC. 1, *Trifolium pratense* L. +, *Ranunculus repens* L. 1, *Alchemilla marsica* Buser +, *Trollius europaeus* L. +, *Veronica beccabunga* L. +, **Mulgedio-Aconitetea:** *Jacobaea alpina* (L.) Moench subsp. *samnitum* (Nyman) Peruzzi 1, **Nardetea strictae:** *Nardus stricta* L. +, *Festuca rubra* L. subsp. *commutata* (Gaudin) Markgr.-Dann. 1, *Brachypodium genuense* (DC.) Roem. & Schult. +, *Plantago maritima* L. subsp. *serpentina* (All.) Arcang. +, *Plantago atrata* Hoppe subsp. *atrata* +, **Elyno-Seslerietea:** *Lotus corniculatus* L. subsp. *alpinus* (DC.) Rothm. 1, *Phyteuma orbiculare* L. +, *Campanula scheuchzeri* Vill. subsp. *scheuchzeri* +, *Galium anisophyllon* Vill. +, *Pulsatilla alpina* (L.) Delarbre subsp. *millefoliata* (Bertol.) D.M.Moser +, **Festuco-Brometea:** *Leontodon hispidus* L. 1, *Briza media* L. 1, *Gymnadenia conopsea* (L.) R. Br. 1, *Trifolium montanum* L. subsp. *rupestre* (Ten.) Nyman 1; **Betulo carpaticae-Alnetea viridis**: *Salix foetida* Schleich. ex DC. +.

Site 4: Fosso Cerruglia (Lazio) (central Italy, Lazio Region)
Aulacomnium palustre (Hedw.) Schwägr.
Calliergonella cuspidata (Hedw.) Loeske
§**Hamatocaulis vernicosus* (Mitt.) Hedenäs
Philonotis rigida Brid.
Plagiomnium cuspidatum (Hedw.) T.J.Kop.

Vegetation type: *Carex acuta* and *C. panicea* comm.

Phytosociological relevé. Date: 14/08/2022; **Samplers:** R. Di Pietro, P. Fortini; **Coordinates:** WGS84: 42.588267°N, 13.335103°E; **Altitude:** 1290 m a.s.l.; **Area:** 20 m^2; **Cover:** (100%); **Rockiness:** (---); **Stoniness:** (---); **Environment**: peat bog **Preliminary syntaxonomic classification**: *Caricion davallianae*

Phytosociological Sample:

Scheuchzerio-Caricetea fuscae: *Carex panicea* L. 2, *Succisa pratensis* Moench 3, *Carex echinata* Murray 2, *Menyanthes trifoliata* L. 2, *Equisetum variegatum* Schleich. ex F.Weber & D.Mohr 1, *Blysmus compressus* (L.) Panz. ex Link 1, *Carex davalliana* Sm., 1, *Eleocharis quinqueflora* (Hartmann) O. Schwarz 1, *Dactylorhiza incarnata* (L.) Soó 1, *Juncus articulatus* L. +, *Eriophorum latifolium* Hoppe +, *Carex rostrata* Stokes +, **Molinio-Arrhenatheretea;** *Carex acuta* L., 3, *Carex leporina* L., 2, *Carex pallescens* L. 2, *Juncus conglomeratus* L. 2, *Agrostis stolonifera* L. subsp. *stolonifera* 1, *Juncus inflexus* L. 1, *Equisetum palustre* L. 1, *Trifolium pratense* L. 1, *Anthoxanthum odoratum* L. 1, *Carex distans* 1, *Equisetum fluviatile* L. 1, *Galium palustre* L. subsp. *elongatum* (C.Presl) Arcang. 1, *Juncus effusus* L. subsp. *effusus* 1, *Lathyrus pratensis* L. subsp. *pratensis* +, *Ranunculus polyanthemoides* Boreau +, *Geum rivale* L. +, *Cardamine apennina* Lihová & Marhold +, *Mentha longifolia* (L.) L.+, **Montio-Cardaminetea:** *Epilobium alsinifolium* Vill. +, *Epilobium obscurum* Schreb +. **Mulgedio-Aconitetea:** *Hypericum tetrapterum* Fr. 1. **Nardetea strictae:** *Deschampsia cespitosa* (L.) P.Beauv. subsp. *cespitosa* 2, *Potentilla erecta* (L.) Raeusch. 2, *Nardus stricta* L. +, **Festuco-Brometea;** *Briza media* L. 1, *Galium verum* L. 1, *Dactylis glomerata* L. subsp. *glomerata* +, *Cerastium arvense* L. +. **Epilobietea angustifolii:** *Angelica sylvestris* L. subsp. *sylvestris* 1, *Epilobium hirsutum* L. 1, *Valeriana officinalis* L. subsp. *officinalis* +.

Site 5: Fosso Gorzano (central Italy, Lazio Region)
Brachythecium rutabulum (Hedw.) Schimp.
Conocephalum salebrosum Szweyk., Buczk. & Odrzyk
Drepanocladus aduncus (Hedw.) Warnst.
§**Hamatocaulis vernicosus* (Mitt.) Hedenäs
Pellia epiphylla (L.) Corda
Pohlia wahlenbergii (F.Weber & D.Mohr) A.L.Andrews

Vegetation type: *Salix hastata* dmarf-shrub community

Phytosociological relevé: Date: 28/08/2022; **Samplers:** R. Di Pietro, G. Tondi; **Coordinates:** WGS84: 42.627136°N, 13.378733°E; **Altitude:** 1640 m a.s.l.; **Area:** 20 m^2; **Cover:** (90%); **Rockiness:** (15%); **Stoniness:** (10%); **Environment:** Boreo-alpine willow low scrubs of the long-snow-covered slopes, at the edge of streams; **Preliminary syntaxonomic classification:** *Betulo carpaticae-Alnetea viridis.*

Phytosociological Sample:

Betulo carpaticae-Alnetea viridis: *Salix hastata* L. 4, *Adenostyles australis* (Ten.) Iamonico & Pignatti 1, *Chaerophyllum hirsutum* L. 1, *Jacobaea alpina* (L.) Moench subsp. *samnitum* (Nyman) Peruzzi 2, **Carpino-Fagetea:** *Cardamine enneaphyllos* (L.) Crantz 1, *Hieracium lachenalii* Suter +, *Veronica urticifolia* Jacq. 1, **Elyno-Seslerietea:** *Pedicularis verticillata* L. subsp. *verticillata* +, *Bistorta vivipara* (L.) Delarbre 1, *Crepis aurea* (L.) Cass. subsp. *glabrescens* (Caruel) Arcang. +, **Thlaspietea rotundifolii:** *Bellidiastrum michelii* Cass. +, *Leucopoa dimorpha* (Guss.) H.Scholz & Foggi 1, *Valeriana montana* L. 1, *Arenaria bertolonii* Fiori +, **Festuco-Brometea:** *Lotus corniculatus* L. +, **Salicetea purpureae:** *Salix apennina* A.K.Skvortsov +, *Salix purpurea* L. subsp. *purpurea* 1, **Montio-Cardaminetea:** *Saxifraga aizoides* L. 2, **Scheuchzerio-Caricetea fuscae**: *Carex frigida* All. 1, *Dactylorhiza maculata* (L.) Soó subsp. *fuchsii* (Druce) Hyl. 1, *Parnassia palustris* L. 1, *Pinguicula vulgaris* L. 2.

Site 6: Castellano stream, confluence with Fosso Cerruglia (central Italy, Lazio Region)
Brachythecium rivulare Schimp.
Brachythecium rutabulum (Hedw.) Schimp.
Conocephalum conicum (L.) Dumort.
Hygrohypnum luridum (Hedw.) Jenn.
Plagiomnium undulatum (Hedw.) T.J.Kop.
Rhynchostegium riparioides (Hedw.) Cardot

Vegetation type: Willow trees gallery wood over a stream.

Phytosociological relevé: Date: 20/08/2022; **Samplers:** R. Di Pietro, P. Fortini, F. Di Pietro; **Coordinates:** WGS84: 42.592317°N, 13.324914°E; **Altitude:** 1265 m a.s.l.; **Area:** 80 m^2; **Cover:** (100%); **Rockiness:** (10%); **Stoniness:** (---).; **Preliminary syntaxonomic classification:** *Carpinion betuli*

Phytosociological Sample:

Carpino-Fagetea: *Corylus avellana* L. 3, *Brachypodium sylvaticum* (Huds.) P.Beauv. 2, *Bromopsis ramosa* (Huds.) Holub subsp. *ramosa* 2, *Pulmonaria vallarsae* A.Kern. subsp. *apennina* (Cristof. & Puppi) L.Cecchi & Selvi 2, *Ranunculus lanuginosus* L. 2, *Viola odorata* L. 2, *Daphne mezereum* L. 1, *Festuca heterophylla* Lam. 1, *Knautia gussonei* Szabó 1, *Melica uniflora* Retz. 1, *Poa nemoralis* L. subsp. *nemoralis* 1, *Polygonatum multiflorum* (L.) All. 1, *Fragaria vesca* L. subsp. *vesca* +, *Aremonia agrimonoides* (L.) DC. subsp. *agrimonoides* +, *Cephalanthera rubra* (L.) Rich. +, *Epilobium montanum* L. +, *Epipactis helleborine* (L.) Crantz +, *Euphorbia dulcis* L. +, *Rubus hirtus* Waldst. & Kit. +, *Vicia sepium* L. +, *Viola riviniana* Rchb. subsp. *riviniana* +, **Salicetea purpureae:** *Salix purpurea* L. 4, *Salix alba* L. 3, **Rhamno-Prunetea:** *Viburnum lantana* L. 2, *Crataegus monogyna* Jacq. 1, *Lonicera xylosteum* L. 1, *Lonicera caprifolium* L. +, *Prunus spinosa* L. subsp. *spinosa* +, **Epilobietea angustifolii:** *Aegopodium podagraria* L. 3, *Chaerophyllum hirsutum* L. 2, *Cardamine impatiens* L. subsp. *impatiens* 1, *Urtica dioica* L. subsp. *dioica* 1, *Chaerophyllum aureum* L. +, *Cirsium arvense* (L.) Scop. +, *Filipendula ulmaria* (L.)

Maxim. +, *Petasites hybridus* (L.) G.Gaertn., B.Mey. & Scherb +, *Dactylorhiza maculata* (L.) Soó subsp. *fuchsii* (Druce) Hyl. +, **Molinio-Arrhenatheretea:** *Dactylis glomerata* L. subsp. *glomerata* 1, *Equisetum palustre* L. 1, *Ranunculus repens* L. 1, *Asperula laevigata* L. +, *Galium palustre* L. subsp. *elongatum* (C.Presl) Arcang. +, *Veronica beccabunga* L. +, *Veronica chamaedrys* L. +, *Deschampsia cespitosa* (L.) P.Beauv. subsp. *cespitosa* +, *Galium mollugo* L.+.

Site 7: Springs within the mild slope of the left side of Castellano stream (central Italy, Lazio Region)
Calliergonella cuspidata (Hedw.) Loeske
Campylium stellatum (Hedw.) Lange & C.E.O.Jensen
Conocephalum conicum (L.) Dumort.
Marchantia polymorpha L. subsp. *polymorpha*
Pellia epiphylla (L.) Corda
Plagiomnium undulatum (Hedw.) T.J.Kop.
Rhynchostegium riparioides (Hedw.) Cardot

Vegetation type: *Carex davalliana* and *C. hostiana* comm.

Phytosociological relevé. Date: 19/08/2022; **Samplers:** R. Di Pietro, P. Fortini, F. Di Pietro; **Coordinates:** WGS84: 42.592067°N, 13.324183°E; **Altitude:** 1275 m a.s.l.; **Area:** 20 m^2; **Cover:** (100%); **Rockiness:** (10%); **Stoniness:** (10%); En**vironment:** peat bog; **Preliminary syntaxonomic classification:** *Caricion davallianae*

Phytosociological Sample:

Scheuchzerio-Caricetea fuscae: *Carex davalliana* Sm. 3, *Carex hostiana* DC. 2, *Carex panicea* L. 1, *Juncus articulatus* L. 2, *Menyanthes trifoliata* L. 2, *Succisa pratensis* Moench 2, *Carex echinata* Murray 1, *Parnassia palustris* L. 1, *Triglochin palustris* L. 1, *Dactylorhiza incarnata* (L.) Soó +, *Pinguicula vulgaris* L. +, **Molinio-Arrhenatheretea:** *Carex acuta* L. 2, *Carex distans* 1, *Carex flacca* Schreb. 1, *Juncus effusus* L. subsp. *effusus* 1, *Juncus inflexus* L. 1, *Pulicaria dysenterica* (L.) Bernh. 1, **Montio-Cardaminetea:** *Saxifraga aizoides* L. +, **Mulgedio-Aconitetea:** *Calamagrostis varia* (Schrad.) Host 1, **Nardetea:** *Deschampsia cespitosa* (L.) P.Beauv. subsp. *cespitosa* 2, *Potentilla erecta* (L.) Raeusch. 2, **Festuco-Brometea:** *Centaurea jacea* L. subsp. *angustifolia* (DC.) Gremli 1, *Briza media* L. +, **Epilobietea angustifolii:** *Eupatorium cannabinum* L. subsp. *cannabinum* 2, **Carpino-Fagetea:** *Cephalanthera rubra* (L.) Rich. +.

Site 8: M. Cima della Laghetta, subalpine belt mires (central Italy, Abruzzo Region)
Ctenidium molluscum (Hedw.) Mitt.
Tortella tortuosa (Hedw.) Limpr.
Gymnostomum calcareum Nees & Hornsch.
**Philonotis rigida* Brid.
Palustriella commutata (Hedw.) Ochyra

Vegetation type: *Carex davalliana* and *C. echinata* comm.

Phytosociological relevé. Date: 12/09/2022; **Samplers:** R. Di Pietro, S. Praleskouskaya, G. Tondi; **Coordinates:** WGS84: 42.579114°N, 13.393047°E; **Altitude:** 1940 m a.s.l.; **Area:** 20 m^2; **Cover:** (100%); **Rockiness:** (---); **Stoniness:** (---); **Environment:** peat bog; **Preliminary syntaxonomic classification:** *Caricion davallianae*

Phytosociological Sample:

Scheuchzerio-Caricetea fuscae: *Carex echinata* Murray 3, *Eleocharis quinqueflora* (Hartmann) O.Schwarz 3, *Carex frigida* All. 2, *Carex panicea* L. 2, *Eriophorum latifolium* Hoppe 2, *Juncus articulatus* L. 2, *Triglochin palustris* L. 2, *Blysmus compressus* (L.) Panz. ex Link 1,

Figure 8. Bryophyte carpet dominated by *Ptychostomum pseudotriquetrum* and *Palustriella falcata* hosting some vascular plant species typical of mire habitats (e.g. *Pinguicula vulgaris*, *Jacobaea alpina* subsp. *samnitum*, *Saxifraga aizoides*) in the Fosso della Pacina sampling site (Photo R. Di Pietro).

Carex davalliana Sm. 1, *Equisetum variegatum* Schleich. ex F.Weber & D.Mohr 1, *Juncus alpinoarticulatus* Chaix 1, *Parnassia palustris* L. 1, **Molinio-Arrhenatheretea:** *Cirsium palustre* (L.) Scop. 2, *Agrostis stolonifera* L. subsp. *stolonifera* 1, *Carex flacca* Schreb. 1, *Equisetum palustre* L. 1, *Juncus inflexus* L. 1, *Prunella vulgaris* L. 1, *Scorzoneroides autumnalis* (L.) Moench 1, *Cynosurus cristatus* L. +, *Trifolium repens* L. +, **Montio-Cardaminetea:** *Alchemilla coriacea* Buser 2, *Epilobium alsinifolium* Vill. 1, **Nardetea strictae:** *Deschampsia cespitosa* (L.) P.Beauv. subsp. *cespitosa* 1, *Luzula campestris* (L.) DC. +, **Festuco-Brometea**: *Linum catharticum* L. 1, *Briza media* L. +, *Cerastium arvense* L. +, *Gentianopsis ciliata* (L.) Ma +.

Discussion

In this study, some montane and subalpine mires of the Laga Mountains were investigated. Despite a significant number of papers published concerning the vascular flora and boreal-type vegetation, the researches concerning the bryophyte flora of the Laga Mountains are very limited. Accordingly, in this study we provided new information useful not only for updating regional and national bryophyte lists, but also for investigating the ecological features of some rare boreal bryophyte species at the southernmost boundaries of their range. Moreover, we analysed the coenological and biogeographical correspondence between the bryophyte species identified and the Habitat types which are currently reported for the Apennines by the EUNIS classification and the 92/43/EEC Habitats Directive.

As expected, the chorological spectrum relating to all the 44 species identified is in accordance with the bioclimatic features of the sites of collection, which are located at the border between the upper-montane and the subalpine belts, and with the ecology of the communities investigated. The Boreal element is dominant and it exhibits higher percentages than the Temperate element, which is dominant when all the bryophytes of the whole Laga mountain territory are considered (Aleffi et al. 1997).

From a national (regional) floristic point of view, nine, out of the forty-four species of bryophytes collected, were found to be new for the Lazio administrative Region and one to be new for the Abruzzo Region. These regional records, which might seem of little interest from a large-scale perspective, become very important when dealing with procedures related to Habitats and biodiversity conservation and with the environmental policies involved in achieving this goal. The majority of the policies for biodiversity safeguarding in Italy, and the related evaluation of the conservation actions applied, are established and managed by the governance of the single administrative Regions, which normally is required to deal with matters of conservation concerning their own territory only. Accordingly, new regional floristic records represent the essential data set through which each administrative region is periodically called upon to implement new and more adequate conservation measures for safeguarding biodiversity or for modifying the existing measures (especially when these records concern rare or protected species or when SAC or other types of protected areas are involved).

From a strictly chorological point of view, our findings are to be considered of a large-scale interest, given that the aforementioned new records also involve a southward extension of the overall range of some of the rare species identified (e.g. *Hamatocaulis vernicosus*, *Ptychostomum cernuum*, *Schljakovia kunzeana*, *Scorpidium cossonii*). The modifications of the known distribution area of species with high biogeographical importance always receive much attention in the field of conservation biology, especially when these modifications concern populations that are more or less isolated or restricted to the very edge of their range. It is not by chance that such species are often attributed an importance similar to that normally given to narrow endemics or rare taxa (Lesica and Allendorf 1995; Rossi and Gentili 2006; Abeli et al. 2018). In fact, edge-range populations are more sensitive to environmental stresses compared to the populations occupying the core of the range, and face a higher risk of extinction when some critical environmental factors undergo significant variations (Abeli et al. 2012; Carbognani et al. 2019). This is precisely what is happening at present in many montane areas of southern Europe (e.g. the Central Apennines) due to the negative effects of global warming. A typical example are the micro-thermic boreal or arctic-alpine communities developed within the subalpine or alpine belt, whose survival is put at risk by the rise in altitude of the more thermophilious grassland and shrubland communities of the underlying bioclimatic belts (Evangelista et al. 2016).

In this perspective, one of the most important findings of our study is the new record for *Hamatocaulis vernicosus*, a species currently included in the Annex II of the Habitats Directive and distributed in North and South America, Asia and throughout Europe, except for the Mediterranean region (Hedenäs et al. 2022). In Italy, *H. vernicosus* is known for the Alps and the northern slope of the Northern Apennines. This new record from the Laga Mountains moves the current distribution limit of *H. vernicosus* in the Italian Peninsula significantly southwards. According to Hedenäs and Eldenäs (2007) and Hedenäs et al. (2022), *H. vernicosus* is known to give rise to two cryptic species (i.e. species indistinguishable from a morphological point of view but well-differentiated molecularly), which exhibit a partly different distribution in Europe. These two cryptic species were found to overlap significantly in central Europe and the Alps, but only one of them (CRS1) occurs in southwestern Europe, while only the other one (CRS2) was found to occur in northern Scandinavia. According to the distribution maps published in Hedenäs et al. (2022), it is not possible to hypothesize to which cryptic species the new *H. vernicosus* population we recorded in the Laga Mountains belong. Indeed, both CRS1 and CRS2 are currently considered to occur along the southern

slope of the Alps and in the Western Balkans, which are the portions of the *H. vernicosus* range closest (in terms of geographical distance) to the Laga Mountains. However, the authors hypothesised that CRS1 only survived the glaciations in refuge areas located in south Europe, whereas CRS2 in refuge areas located in northern and/or eastern Europe. Accordingly, new genetic analysis to be carried out on the southernmost edge-range populations of *H. vernicosus* from the Laga Mountains could provide important information to confirm: i) which of the two aforementioned cryptospecies is actually present in the Central Apennines, ii) whether CRS1 has also survived in glacial refuges occurring in the Italian Peninsula in addition to those already known for the Iberian Peninsula and the Balkans.

Figure 9. A specimen of *Hamatocaulis vernicosus* mixed with *Pellia epiphylla* from Mount Pelone site.

According to Hedenäs et al. (2022), *H. vernicosus* is experiencing an expansion phase in central Europe thanks to the new opportunities created by the implementation of extensive agriculture that gives an advantage to less competitive plants, such as bryophytes, over the vascular plants (Singh et al. 2021). Obviously, this cannot happen in the Apennines given that *H. vernicosus* is found exclusively in primary (almost unexplored) sites of the upper montane and subalpine belts which are not, or only marginally, affected by the presence of human activity or grazing livestock (and there is very little chance that an implementation of grazing will happen in the near future considering the socio-economic changes that have affected the montane areas over the last fifty years). Indeed, *H. vernicosus* is seriously at risk of extinction in the Apennines due to the constant increase in temperatures and the simultaneous decrease in snowfall. For the foregoing reasons constant monitoring of the existing populations of this species is urgently required. It is quite surprising, therefore, that, as a boreal relict species included in Annex II of the Habitats Directive, *H. vernicosus* falls into a low threat category in Italy (LC in Puglisi et al. 2024), despite having already been classified as VU-Vulnerable at pan-European level (see Hodgetts and Lockhart 2020). Probably the fact that this species is currently reported for five, out of the seven northern Italy administrative regions facing the southern slope of the Alps, meant that it has been considered as a non-risk species. In contrast, other countries crossed by the Alps, such as Germany or Switzerland, consider it at EN and NT conservation status, respectively. This new record of *H. vernicosus* for the Laga Mountains, could lend support to a proposal for a change in its conservation status at least at regional level, especially considering the somewhat scattered occurrence in the Apennines of its preferential hosting habitat type (*Caricion davallianae* grasslands). On the other hand, in other Mediterranean countries, such as Spain and Bulgaria, this species is considered EN-Endangered and VU-Vulnerable, respectively, and in Bulgaria, *H. vernicosus* is also included in annex II of the Bulgarian Biodiversity Protection law (Ganeva and Natcheva 2004; Natcheva et al. 2006).

In addition to *H. vernicosus*, there are further two species, *Scorpidium cossonii* (Schimp.) Hedenäs and *Schljakovia kunzeana* (Huebener) Konstant. & Vilnet, whose Italian distribution was known for northern Italy only (Aleffi et al. 2023). The considerations made for *Hamatocaulis vernicosus* are largely valid also for *Scorpidium cossonii*, a species of pre-Quaternary Arctic origin that survived the glaciations in some cold areas of the central and southern Europe (Hedenäs and Eldenäs 2008; Hedenäs 2009). *S. cossonii* is described as a taxon typical of the species-rich calcareous fens, a habitat type which is described as currently endangered by many factors, such as land-use changes, nutrient enrichment, and fragmentation (Kophimai et al. 2014). The new record for the Laga Mountains acts as the new southernmost distribution limit for this species in the Italian Peninsula.

As far as *Schljakovia kunzeana* is concerned, the new finding of the species in the Laga Mountains is located along the current southernmost limit of its range, more or less at the same latitude of its south-western limit (Iberian Peninsula) and its south-eastern limit (Southern Balkans) (see GBIF at https://www.gbif.org/species/4891040). Indeed, the already established southernmost records of *S. kunzeana* for the Iberian Peninsula are located in the mountains of Navarra and Asturias in northwestern Spain and in the Central Pyrenees (Casas Sicart 1986; Fernández Ordoñez and Collado Prieto 2003; Dort 2021), whereas those for the Balkan Peninsula are reported for the Pirin massif and the Rila Mountains in Bulgaria (Ganeva and Natcheva 2003).

The chorological identity of *Ptychostomum cernuum* is a little different. This species is currently reported for three administrative regions of northern Italy (Lombardy, Piedmont, and Trentino-Alto Adige) only based on old data deriving from collections published before 1968 (Aleffi et al. 2023). As a consequence, this finding on the Laga Mountains represents the first record of *P. cernuum* in the last fifty years for the entire Italian Peninsula, as well as being the first record of this species for the entire Apennines. Curiously, although this boreal species is cur-

rently absent throughout the rest of central and southern Italy (where there are several montainous massifs characterized by subalpine and alpine belts rich in circumboreal species), it reappears in Sicily where populations of this species have recently been reported (Puglisi and Privitera 2018) for the Etna Volcano, at relatively low altitude (about 1000 m a.s.l.). For this reason, the new record of *P. cernuum* for the Laga Mountains area, although it is the first for the Apennines, does not imply any further southern extension of the range currently known for this species, either on a global or Italian country level.

Many of the bryophyte species found in the study area represent diagnostic species of different Habitats listed in the European conservation Directives. On the basis of the EUNIS European Habitats classification (Chytrý et al. 2020), we found that Habitat Q42 – Extremely rich moss-sedge fen, and Habitat Q41 – Alkaline, calcareous, carbonate-rich small-sedge spring fen, are those including the majority of the aforementioned bryophyte diagnostic species (Q42: *Aneura pinguis*, *Aulacomnium palustre*, *Campylium stellatum*, *Hamatocaulis vernicosus*, *Ptychostomum pseudotriquetrum*; Q41 *Campylium stellatum*, *Palustriella commutata*, *Philonotis calcarea*, *Ptychostomum pseudotriquetrum*). The diagnosis of Habitat Q42 refers to base-rich fens classified in alliances, such as *Saxifrago-Tomentypnion* and *Sphagno warnstorfii-Tomentypnion nitentis*, which includes associations always dominated by bryophytes, with calcium-tolerant *Sphagnum* mosses playing the leading role. Habitat Q42 is not reported for the Central Apennines at present, its southernmost limit being located in the Northern Apennines. Instead, Habitat Q41 would certainly be among the most suitable to encompass some of the communities we investigated (especially those we sampled in sites 1, 2, 3, 8). Indeed, Habitat Q41 is known to include small-sedge communities, and, among these, those belonging to *Caricion davallianae* and *Caricion viridulo-trinervis*. Moreover, Q41 has already been reported for the Central Apennines (see Q41 map in Chytrý et al. 2020). In addition to the aforementioned Q41 diagnostic bryophytes, the communities we sampled exhibited many vascular plant species (most of them playing a dominant role in the communities investigated), which are also considered to be diagnostic for this habitat, such as *Carex davalliana*, *C. viridula*, *C. lepidocarpa*, *Eleocharis quinqueflora*, *Eriophorum latifolium*, *Juncus alpinoarticulatus*, *Parnassia palustris*, *Pinguicula vulgaris*, *Tofieldia calyculata*.

EUNIS Habitat Q43 (Tall-sedge base-rich fen), which is described as including "tall-sedge fens and medium to tall graminoids over a ground carpet of rich-fen bryophytes", acts as a possible alternative reference, especially for the communities developed over larger dimension flat landforms. This environmental type could be applied to the communities we found at Fosso Cerruglia and along the banks of the Castellano river (sites 4 and 7, respectively). In these sites, the physiognomic dominance is given by tall sedges (e.g. *Carex acuta*, *C. panicea*, *C. pallescens*) and other medium-size species (*Juncus effusus*, *J. inflexus*, *Deschampsia cespitosa*), together with species considered to be diagnostic and frequently occurring in Q43 habitat (e.g. *Carex echinata*, *C. rostrata*, *Menyanthes trifoliata*, *Potentilla erecta*, *Succisa pratensis*). Regarding bryophytes considered as diagnostic in Habitat Q43, we found *Aneura pinguis* and *Campylium stellatum*. In addition, we found *Calliergonella cuspidata*, *Ctenidium molluscum*, *Palustriella commutata*, *Ptychostomum pseudotriquetrum* as constant species. It is worth highlighting that Habitat Q43 is one of the two habitats, out of those identified in this study, exhibiting the highest number of bryophyte constant species. The other one is Habitat Q23 - Relict mire of Mediterranean mountains. Habitat Q23 characterizes the oligo-mesotrophic mires occurring in the montane and subalpine belts over siliceous bedrocks and exhibits a peculiar geographical distribution that comprises the Balkans, the mountains of Corsica and the Sierra Nevada massif in southern Spain. The diagnostic bryophyte species we collected in our samples are *Philonotis seriata*, *Ptychostomum pseudo triquetrum* and *Sarmentypnum exannulatum*. The finding of this habitat in the middle of the Italian Peninsula could be considered evidence for a natural geographical connection bridging an anomalous biogeographical gap along the W-E (or E-W) alignment of the Mediterranean mountain ranges. Moreover, the Laga Mountains, being a siliceous Mediterranean massif characterized by acidic soil, correspond significantly to the diagnosis of Habitat Q23, especially considering that the communities we sampled are developed at the edge of melting snow streams in the upper montane and subalpine belts. Last, but not least, the Central Apennines are biogeographically strictly related to the Balkans (core area of Q23 Habitat) and form the Apennine-Balkan biogeographical Province (see Rivas-Martínez et al. 2004). Despite all this, Habitat Q23 cannot serve as useful reference for the communities described in this paper. In fact, the vascular plant species reported in the EUNIS Habitat factsheet as those bearing the highest diagnostic coefficient for habitat Q23 are all species displaying a restricted Balkan distribution (e,g. *Pinguicula balcanica* Casper, *Gymnadenia frivaldii* Hampe ex Griseb., *Plantago gentianoides* Sibth. & Sm., *Primula frondosa* Janka, *Dactylorhiza cordigera* (Fr.) Soó, *Carex bulgarica* (Domin) Lazare). Moreover, the syntaxonomic references reported (*Narthecion scardici*, *Festucion frigidae* and *Caricion intricatae*) are strictly related to the Balkans, Sierra Nevada and Corsica, respectively. Obviously, if, as a result of our study, it should be established that the Central Apennines too are a suitable site for hosting the Q23 Habitat, then the whole diagnosis of this Habitat will need to be revised.

EUNIS Habitat Q45 includes several of the species and communities we detected, although its diagnosis and current distribution "*Fens developed on open substrates constantly flushed by icy, base-rich water alongside small rivers, springs or glaciers in the alpine belt of European mountains and in the Arctic*" would not support its occurrence in a

Mediterranean mountain range such as the Apennines. However, the presence in our samples of Q45 diagnostic bryophytes, such as *Ptychostomum pseudotriquetrum*, *Palustriella commutata*, *Campylium stellatum*, together with several diagnostic vascular plant species, testifies to the importance of the Laga Mountains for the conservation of boreal species during the post-glacial period. This statement is particularly supported by the finding of *Schljakovia kunzeana* which is currently considered as diagnostic for extreme glacial habitats, such as S11 "*Shrub tundra*" and S12 "*Moss and lichen tundra*", both limited to the northern sector of Scandinavia.

Our attempts to find a correspondence between the bryophytes found in the study area and the diagnostic species lists occurring in Annex I, of the EUR 23 interpretation manual of Directive 92/43/EEC, reveal that the information obtained from Annex I is limited and partially indeterminate. This is probably due to the lower degree of detail used in Annex I in evaluating both the numerical consistency of the pools of species typical of a given Habitat and, more specifically, the ecological (and coenological) role of the bryophyte component within each habitat type. Habitat 7160 (*Fennoscandian mineral-rich springs and springfens*) is the one showing the highest number of diagnostic bryophyte species, among those we collected during our sampling. This evidence is quite surprising, even just considering the diagnosis of Habitat 7160 and the geographical distribution declared in it. However, this Habitat would not seem like a good reference for the communities we sampled also from a floristic point of view, since only *Epilobium alsinifolium* was found in our surveys among all the vascular plant species reported as diagnostic for 7160 in the Manual of interpretation. It is no coincidence that, the Italian Manual for Habitats Directive (Biondi et al. 2009) excludes the presence of this habitat from the whole Italian territory.

The Habitat types exhibiting the greatest coherence with the cryptogamic and vascular flora occurring in our sampled sites, according to the EUR 28 Manual, are certainly Habitats 7220* (*Petrifying springs with tufa formation*) and 7230 (*Alkaline fens*). Both these habitats share numerous diagnostic species (e.g. *Ptychostomum pseudotriquetrum*, *Parnassia palustris*, *Pinguicula vulgaris*, *Saxfraga aizoides*, *Tofieldia calyculata*). However, the environments characterized by the two aforementioned habitats appear to be very different from each other, as can be deduced even just by considering the phytosociological alliances proposed as syntaxonomic reference in the Manual. Habitat 7220* is characterized by communities mainly developed near springs and dripping walls, normally in shady locations, which are generally classified in the alliance *Cratoneurion commutati*. This type of vegetation does not correspond, if not very partially, to the communities we detected. In fact, at least in Italy, Habitat 7220 is not linked to the mountain environment, but is widely distributed in all the Italian administrative Regions, including Sicily and Sardinia.

However, as emerged from our samples, the bryophytes listed as diagnostic for Habitat 7220* (*Eucladium verticillatum*, *Philonotis calcarea*, *Hamatocaulis vernicosus*, *Ptychostomum pseudotriquetrum*, *Scorpidium cossonii*) show high frequency and coverage values also in a completely different environment, such as the *Caricion davallianae* meadows. This grassland type closely matches Habitat 7230, which, accordingly, is to be considered the most suitable reference for the communities we sampled, both considering their ecology and structure, and the syntaxonomic classification provided in the diagnosis itself (i.e. small sedge and brown moss mire communities belonging mainly to *Caricion davallianae* developed on soils permanently waterlogged with the water table at, or slightly above or below, the substratum).

The bryophytes that the Manual EUR 28 reports as diagnostic for the Habitat 7230 are *Campylium stellatum*, *Calliergonella cuspidata*, *Ctenidium molluscum*, *Ptychostomum pseudotriquetrum*, *Scorpidium cossonii.* However, compared to Habitat 7220*, there is a significantly higher number of diagnostic vascular plant species. What is apparently not entirely consistent comparing the study area with the Habitat diagnosis, is that Habitat 7230 is normally associated with calcareous substrates with neutral alkaline pH values, and dominated by calciphilous small sedges. This is actually not exactly in line with the soil characteristics of the Laga Mountains, which especially in the highest bioclimatic belts are characterized by typical acidophilous communities, such as the *Nardus stricta* L., and *Patzkea paniculata* (L.) G.H.Loos communities among the grasslands, the acidophilic beech forest of the upper montane belt with *Veronica urticifolia* Jacq. and *Gymnocarpium dryopteris* (L.) Newman and of the *Vaccinium myrtillus* L. heathlands throughout the lower subalpine belt (see Pedrotti, 1982; Biondi et al. 2009; Blasi et al. 2003; Di Pietro 2007; Di Pietro et al. 2007). A plausible explanation for this apparent contradiction could be that vascular plants are more affected by the influence of the bedrock than bryophytes because they are characterized by roots that penetrate the soil at greater depths. Having rhizoids anchored to the substrate to a depth of only a few millimeters and absorbing nutrients directly from the atmosphere, bryophytes are less strongly influenced by the type of substrate. This weak influence is likely to be more pronounced in environments such as those investigated in this study (mires developed at the bottom of subalpine north facing gullies), where the upper soil layers tend to lose part of their acidity being washed away by rain or snow.

If only the type of substrate and the pH values are considered, Habitat 7240 (Alpine pioneer formations of *Caricion bicoloris-atrofuscae*) would be the most suitable to be used as reference, as it refers to a neutral or slightly acidic pH. However, in neither the EUR23 Interpretation Manual, nor the Italian version of it, is there a list of diagnostic bryophyte species for this habitat, apart from a coenological reference to a "*Scorpidium revolvens-Carex saxatilis*

community". Instead, there are several vascular plant species listed as diagnostic for Habitat 7240, including some occurring as dominant in the communities we sampled (e.g. *Carex frigida*, *Juncus alpinoarticulatus*, *J. arcticus*).

The remaining habitats as hosting some of the bryophyte species detected in the sampled area (i.e. 7140; 7310) cannot be taken into consideration, as they are both strictly related to the peatbogs of Northern Europe and characterized by the absolute dominance of *Sphagnum* species in their bryophyte component. Finally, Habitat 9050, which includes among its diagnostic species *Brachythecium rivulare*, *Plagiomnium undulatum*, *P. cuspidatum*, actually concerns open coniferous forest vegetation totally unrelated to the fen and mires communities we investigated.

It emerges that the choice of the habitat to which to assign the communities we detected may not be unambiguous, depending on whether the interpretations are made using the EUNIS Habitats factsheets or the EUR28 Habitat Interpretation manual. If we refer to the EUNIS factsheets it is possible to identify two different habitats (i.e. Q41 for the small pools dominated by small sedge communities and Q43 for the larger pools characterized by bigger size sedge species). Instead, if we refer to the EUR28 Interpretation Manual there would seem to be only a single Habitat type (7230) to which to assign both of the above-mentioned community types. At the same time, however, it is evident that EUNIS habitats Q41 and Q43 are partially overlapping from both a floristic and an ecological point of view so that the choice to consider them as two separate habitats may not be fully shared by the scientific community. Consequently, the uncertainty on which of the two interpretations should be considered the most correct, the one proposed by the EUNIS factsheets or the one proposed by the EUR28 Manual. This paper does not have necessary research data to provide a solution to this question. Apparently, at least in our study case, the EUNIS classification is able to identify two distinct habitats as it uses greater detail than the EUR 28 Manual in the resolution and description of the environmental pattern of the mires and fen occurring in the study area. It seems that the EUNIS classification interpreted the communities using a higher detail scale than that adopted by the EUR 28 Manual. However, the issue of the scale adopted may not be the one to be called into question and the differences between the two aforementioned classification systems have to be attributed to other factors. In fact, in the EUNIS terrestrial habitat classification with crosswalks to Annex I (Schaminée et al. 2012), as reported by the European Environment Agency updated to 2021 (EUNIS 2021), Habitat Q41(D4.2a) corresponds to Annex I 7230 while Habitat Q43 (D4.2b) corresponds to Annex I 7210. Therefore, rather than a simple "quantitative" issue attributable to the scale of observation, there would seem to have been real "qualitative" differences which gave rise to such an interpretation of the aforementioned Habitats.

Conclusions

This study made it possible to fill some knowledge gaps on the presence and distribution of relict bryophyte species of boreal origin in the high altitude bioclimatic belts of the Central Apennines. Nine species of bryophytes were found to be new records for the Lazio administrative Region and one species for the Abruzzo administrative region. For some of these species (e.g. *Hamatocaulis vernicosus*, *Schljakovia kunzeana* and *Scorpidium cossonii*), the new findings have led to an extension of the southernmost limit of their distribution range (at the national and global scale). Of particular interest are the new records of *Hamatocaulis vernicosus*, a species currently included in Annex II of the Habitats Directive, which was still unknown for the Apennines.

The correspondence between the bryophyte species identified and the Habitats available using the EUNIS factsheet and the 92/43/EEC Directive Interpretation Manual led to results that were not completely in agreement in terms of number of species considered and Habitat type involved. The EUNIS classification highlighted two possible Habitats to be used as reference (Q41 and Q43), whereas the Habitat directive Manual highlighted just one Habitat (7230).

The amount of information provided by the EUNIS expert classification system was found to be greater and more complete than that provided by the Habitats Directive Interpretation Manual overall. Based on a continuously updated database of phytosociological surveys and syntaxonomic framework (EuroVegChecklist), the EUNIS factsheets prove to be more effective in providing useful qualitative and quantitative information regarding the cenological role of bryophytes. In contrast, the information provided by the EUR28 interpretation Manual was found to be a little flatter, especially owing the fact that it was not directly derived from statistically-derived diagnostic species. Moreover, the EUR 28 Manual was sometimes found to be deficient in providing information on the ecological role of the diagnostic species and lacking in updated syntaxonomic references to be used for the correct identification of Habitats.

The importance of the Habitats Directive in the management of the environment is clearly recognized in all the European Union countries. All the implications, not only scientific, but also administrative, bureaucratic, and legal linked to the identification, monitoring and assessment of EU Habitats are also recognized. Updated taxonomic, syntaxonomic and ecological information deriving from a robust basis of georeferenced field surveys and validated through publications in scientific journals would therefore be an essential and indispensable help for all the bodies responsible for the management and conservation of the Natura 2000 sites. The need for effective tools which could help in procedures of habitat identification and interpretation (see Bonari et al. 2021) is extremely pressing for the high-altitude habitats of the Mediterranean mountains. Indeed, these are concretely at risk of extinction as

a consequence of progressive and increasingly intense global warming and of greater competition from the plant communities normally developed at lower altitudes. The new floristic, chorological, and coenological data provided by our study confirm the importance of undertaking field sampling campaigns, which are the only way of creating deeper knowledge usable for developing an increasingly efficient network of measures to safeguard biodiversity.

Funding

The research was in part supported by private funds of the authors and in part by: i) National Recovery and Resilience Plan (NRRP), Mission 4 Component 2: Investment 1.4 - Call for tender No. 3138 of 16 December 2021, rectified by Decree n.3175 of 18 December 2021 of Italian Ministry of University and Research; Award Number: Project code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, Project funded by the European Union – "NextGenerationEU NBFC". A) R. Di Pietro: CUP B83C22002950007, Project title "National Biodiversity Future Center; ii) Ateneo Sapienza progetti medi: prot. RM123188F7AAEE40 Resp. Romeo Di Pietro.

Acknowledgments

The authors wish to acknowledge the colleague A. Alegro, the anonymous rewiewer and the subject Editor for valuable feedbacks on an earlier version of the manuscript. The authors wish also to thank the colleagues from University of Brno S. Kubešová, E. Mikulášková, T. Peterka, P. Hájková, M. Hájek for their help in the identification of some specimens.

References

Abeli T, Rossi G, Gentili R, Mondoni A, Cristofanelli P (2012) Response of alpine plant flower production to temperature and snow cover fluctuation at the species range boundary. Plant Ecology 213(1): 1–13. https://doi.org/10.1007/s11258-011-0001-5

Abeli T, Vamosi JC, Orsenigo S (2018) The importance of marginal population hotspots of cold-adapted species for research on climate change and conservation. Journal of Biogeography 45(5): 977–985. https://doi.org/10.1111/jbi.13196

Aleffi M, Cortini Pedrotti C (1991) Check-list delle Briofite note in Abruzzo. In: Mastracci M (Ed.) Atti del Congresso Internazionale di Briologia (L'Aquila, 15–26 luglio 1991): 13–38.

Aleffi M, Cortini Pedrotti C, Schumacker R (1997) Flora briologica dei Monti della Laga (ltalia centrale). Webbia 52(1): 1–41. https://doi.org/10.1080/00837792.1997.10670631

Aleffi M, Cogoni A, Poponessi S (2023) An updated checklist of the bryophytes of Italy, including the Republic of San Marino and Vatican City State. Plant Biosystems 157(6): 1259–1307. https://doi.org/10.1080/11263504.2023.2284136

Arcangeli G (1887) Sopra alcune crittogame raccolte nel Piceno e nell'Abruzzo. Atti della Società toscana di scienze naturali, residente in Pisa Memorie 5: 243–246.

Barsali E (1914) Frammenti d'Epaticologia italiana. Bullettino della Società Botanica italiana 6: 41–44.

Bartolucci F, Peruzzi L, Galasso G, Albano A, Alessandrini A, Ardenghi NMG, Astuti G, Bacchetta G, Ballelli S, Banfi E, Barberis G, Bernardo L, Bouvet D, Bovio M, Cecchi L, Di Pietro R, Domina G, Fascetti S, Fenu G, Festi F, Foggi B, Gallo L, Gottschlich G, Gubellini L, Iamonico D, Iberite M, Jiménez-Mejías P, Lattanzi E, Marchetti D, Martinetto E, Masin RR, Medagli P, Passalacqua NG, Peccenini S, Pennesi R, Pierini B, Poldini L, Prosser F, Raimondo FM, Roma-Marzio F, Rosati L, Santangelo A, Scoppola A, Scortegagna S, Selvaggi A, Selvi F, Soldano A, Stinca A, Wagensommer RP, Wilhalm T, Conti F (2018) An updated checklist of the vascular flora native to Italy. Plant Biosystems 152(2): 179–303. https://doi.org/10.1080/11263504.2017.1419996

Bartolucci F, Domina G, Adorni M, Andreatta S, Angiolini C, Bacchetta G, Banfi E, Barberis D, Bertani G, Bonari G, Buccomino G, Calvia G, Caputo P, Cavallaro V, Conti F, Cuena-Lombraña A, D'Aleo F, D'Amico FS, De Fine G, Del Guacchio E, De Matteis Tortora M, De Santis E, Fois M, Di Pietro F, Di Pietro R, Fanfarillo E, Fiaschi T, Forte L, Galasso G, Laface VLA, Lallai A, Lonati M, Longo C, Longo D, Magrini M, Mei G, Menghi L, Menini F, Morabito A, Musarella CM, Nota G, Palermo DC, Passalacqua NG, Pazienza G, Peruzzi L, Pierini B, Pinzani L, Pisani G, Polverelli L, Prosser F, Salerno G, Salerno P, Santi F, Selvaggi A, Spampinato G, Stinca A, Terzi M, Valentini F, Vitale S, Wagensommer RP, Lastrucci L (2022) Notulae to the Italian native vascular flora: 14. Italian Botanist 14: 119–131. https://doi.org/10.3897/italianbotanist.14.97813

Biondi E, Ballelli S, Allegrezza M, Taffetani F, Frattaroli AR, Guitan J, Zuccarello V (1999) La vegetazione di Campo Imperatore (Gran Sasso d'Italia). Braun-Blanquetia 16: 33–53.

Biondi E, Allegrezza M, Ballelli S, Taffetani F (2000) La vegetazione del Corno Grande (2912m) nel Gran Sasso d'Italia (Appennino centrale). Fitosociologia 37: 152–168. [The vegetation of the mount Corno Grande in the Gran Sasso massif] [In Italian]

Biondi E, Blasi C, Burrascano S, Casavecchia S, Copiz R, Del Vico E, Galdenzi D, Gigante D, Lasen C, Spampinato G, Venanzoni R, Zivkovic L (2009) Manuale Italiano di interpretazione degli habitat della Direttiva 92/43/CEE. Società Botanica Italiana. Ministero dell'Ambiente e della tutela del territorio e del mare, D.P.N. [Available online at] http://vnr.unipg.it/habitat [accessed on 2023, Sept 22]

Biondi E, Blasi C, Allegrezza M, Anzellotti I, Azzella MM, Carli E, Casavecchia S, Copiz R, Del Vico E, Facioni L, Galdenzi D, Gasparri R, Lasen C, Pesaresi S, Poldini L, Sburlino G, Taffetani F, Vagge I, Zitti S, Zivkovic L (2014) Plant communities of Italy: The Vegetation Prodrome. Plant Biosystems 148(4): 728–814. https://doi.org/10.1080/11263504.2014.948527

Blasi C (1994) Fitoclimatologia del Lazio. Fitosociologia 27: 151–175.

Blasi C, Di Pietro R, Fortini P, Catonica C (2003) The main Plant community types of the alpine belt of the Apennine chain. Plant Biosystems 137(1): 83–110. https://doi.org/10.1080/11263500312331351361

Blasi C, Di Pietro R, Pelino G (2005) The vegetation and landscape of alpine belt karst-tectonic basin in the Majella mountain (central Apennines). Plant Biosystems 139: 357–385. https://doi.org/10.1080/11263500500350150

Bonari G, Fantinato E, Lazzaro L, Sperandii MG, Acosta ATR, Allegrezza M, Assini S, Caccianiga M, Di Cecco V, Frattaroli A, Gigante D, Rivieccio G, Tesei G, Valle B, Viciani D, Albani Rocchetti G, Angiolini C, Badalamenti E, Barberis D, Barcella M, Bazan G, Bertacchi A, Bolpagni R, Bonini F, Bricca A, Buffa G, Calbi M, Cannucci S, Cao Pinna L, Caria MC, Carli E, Cascone S, Casti M, Cerabolini BEL, Copiz R, Cutini M, De Simone L, De Toma A, Dalle Fratte M, Di Martino L, Di Pietro R, Filesi L, Foggi B, Fortini P, Gennaio R, Gheza G, Lonati M, Mainetti A, Malavasi M, Marcenò C, Micheli C, Minuzzo C, Mugnai M, Musarella CM, Napoleone F, Nota G, Piga G, Pittarello M, Pozzi I, Praleskouskaya S, Rota F, Santini G, Sarmati S, Selvaggi A, Spampinato G, Stinca A, Tozzi FP, Venanzoni R, Villani M, Zanatta K, Zanzottera M, Bagella S (2021) Shedding light on typical species: Implications for habitat monitoring. Plant Sociology 58(1): 157–166. https://doi.org/10.3897/pls2020581/08

Bottini A (1913) Spigolature briologiche N. 2. Atti della Società toscana di scienze naturali, residente in Pisa Memorie 29: 149–195.

Braun-Blanquet J (1964) Pflanzensoziologie. Grundzüge der Vegetationskunde. Springer Verlag. https://doi.org/10.1007/978-3-7091-8110-2

Carbognani M, Piotti A, Leonardi S, Pasini L, Spanu I, Vendramin GG, Tomaselli M, Petraglia A (2019) Reproductive and genetic consequences of extreme isolation in *Salix herbacea* L. at the rear edge of its distribution. Annals of Botany 124(5): 849–860. https://doi.org/10.1093/aob/mcz129

Casas Sicart C (1986) Catálogo de los briófitos de la vertiente española del Pirineo Central y de Andorra. Collectanea Botanica 16(2): 255–321.

Chytrý M, Danëls FJA, Di Pietro R, Koroleva N, Mucina L (2015) Nomenclature adjustments and new syntaxa of the arctic, alpine and oro-Mediterranean vegetation. Hacquetia 14(1): 103–114. https://doi.org/10.1515/hacq-2015-0004

Chytrý M, Hennekens SM, Jiménez-Alfaro B, Knollová I, Dengler J, Jansen F, et al. (2016) European Vegetation Archive (EVA): an integrated database of European vegetation plots. Applied Vegetation Science 19: 173–180. https://doi.org/10.1111/avsc.12191

Chytrý M, Tichý L, Hennekens SM, Knollová I, Janssen JAM, Rodwell JS, Peterka T, Marcenò C, Landucci F, Danihelka J, Hájek M, Dengler J, Novák P, Zukal D, Jiménez-Alfaro B, Mucina L, Abdulhak S, Aćić S, Agrillo E, Attorre F, Bergmeier E, Biurrun I, Boch S, Bölöni J, Bonari G, Braslavskaya T, Bruelheide H, Campos JA, Čarni A, Casella L, Ćuk M, Ćušterevska R, De Bie E, Delbosc P, Demina O, Didukh Y, Dítě D, Dziuba T, Ewald J, Gavilán RG, Gégout J-C, Giusso del Galdo GP, Golub V, Goncharova N, Goral F, Graf U, Indreica A, Isermann M, Jandt U, Jansen F, Jansen J, Jašková A, Jiroušek M, Kącki Z, Kalníková V, Kavgacı A, Khanina L, Korolyuk AY, Kozhevnikova M, Kuzemko A, Küzmič F, Kuznetsov OL, Laiviņš M, Lavrinenko I, Lavrinenko O, Lebedeva M, Lososová Z, Lysenko T, Maciejewski L, Mardari C, Marinšek A, Napreenko MG, Onyshchenko V, Pérez-Haase A, Pielech R, Prokhorov V, Rašomavičius V, et al. (2020) EUNIS Habitat Classification: Expert system, characteristic species combinations and distribution maps of European habitats. Applied Vegetation Science 23: 648–675. https://doi.org/10.1111/avsc.12519

Conti F, Bartolucci F (2016) The vascular flora of Gran Sasso and Monti della Laga National Park (Central Italy). Phytotaxa 256(1): 1–119. https://doi.org/10.11646/phytotaxa.256.1.1

Conti F, Tinti D (2008) Il Lago di Campotosto e la sua Flora. Litografia Brandolini, Sambuceto di S. Giovanni Teatino, Chieti, 160 pp.

Cortini Pedrotti C (2001) Flora dei Muschi d'Italia. Sphagnopsida, Andreaeopsida, Bryopsida (I parte). Delfino Editore, 1–817.

Cortini Pedrotti C (2005) Flora dei Muschi d'Italia. Bryopsida (II parte). Roma, Ed. Antonio. Delfino, 818–1235.

Cortini Pedrotti C, Schumacker R, Aleffi M, Ferrarini E (1991) A critical catalog of the Bryophytes of the Apuan Alps (Tuscany, Italy). Bulletin de la Société Royale des Sciences de Liège, 60 (4–5): 149–361.

Davies CE, Moss D, Hill MO (2004) EUNIS Habitat Classification. Copenhagen: European Environment Agency.

Di Pietro R (2007) Coenological and syntaxonomical analysis of the beech woodlands of the Laga Mountains (Central Italy). Biogeographia, nuova serie 28: 45–118. https://doi.org/10.21426/B6110077

Di Pietro R (2010) Phytosociological features of *Sesleria calabrica* (Poaceae), an endemic species of Pollino-Orsomarso mountains (southern Italy). Acta Botanica Gallica 157(3): 539–554. https://doi.org/10.1080/12538078.2010.10516229

Di Pietro R, Conti F, Vannicelli Casoni L (2001) On the presence of a new *Linario-Festucion dimorphae* association on Laga Mountains (Central Italy). Fitosociologia 38(1): 67–75.

Di Pietro R, Catonica C, Copiz R (2007) Sulla presenza di *Vaccinium gaultherioides* Bigelow in Italia centrale. Lavori della Società Italiana di Biogeografia (Biogeographia), nuova serie 28: 275–285. https://doi.org/10.21426/B6110079

Di Pietro R, Tondi G, Minutillo F, Bartolucci F, Tinti D, Cecchetti S, Conti F (2008) Ulteriore contributo alla conoscenza della flora vascolare dei Monti della Laga (Appennino centrale). Webbia 63(1): 55–67. https://doi.org/10.1080/00837792.2008.10670833

Di Pietro R, Fröhner SE, Gottschlich G, Minutillo F, Fortini P, Tondi G (2016) A new floristic contribution for the Central Apennines with biogeographical considerations. Atti Società Toscana di Scienze naturali, Memorie, serie B 122(2015): 49–99.

Di Pietro R, Terzi M, Fortini P (2017) A revision of the high-altitude acidophilous and chionophilous grasslands of the Apennines. Phytocoenologia 47(3): 261–304. https://doi.org/10.1127/phyto/2017/0162

Dort K van (2021) Notes on some interesting forest bryophytes from northern Spain. Boletín de la Sociedad Española de Briología 52–53(2019): 63–68.

Düll R (1983) Distribution of European and Macaronesian liverworts (Hepaticophytina). Bryologische Beiträge 2: 1–115.

Düll R (1984) Distribution of the European and Macaronesian mosses (Bryophytina). Part I. Bryologische Beiträge 4: 1–113.

Düll R (1985) Distribution of the European and Macaronesian mosses (Bryophytina). Part II. Bryologische Beiträge 5: 110–232.

EUNIS (2021) EUNIS terrestrial habitat classification 2021_1 with crosswalks to Annex I in separate rows. https://www.eea.europa.eu/ds_resolveuid/31bce053476c488e82ec1598ea3caeab [Accessed 10.01.2024]

European Commission (2013) Interpretation manual of European Union habitats - EUR 28. E. C., DG ENVIRONMENT, Bruxelles.

Evangelista A, Frate L, Carranza ML, Attorre F, Pelino G, Stanisci A (2016) Changes in composition, ecology and structure of high-mountain vegetation: A re-visitation study over 42 years. AoB Plants 8: 1–11. https://doi.org/10.1093/aobpla/plw004

Fernández Ordoñez MC, Collado Prieto MA (2003) Briófitos de la Reserva Natural Integral de Muniellos, Asturias. Consejería de Medio Ambiente, Ordenación del Territorio e Infraestructuras del Principado de Asturias. KRK Ediciones, Oviedo, 230 pp.

Foggi B (1990) Analisi fitogeografica del Distretto Appenninico Tosco-Emiliano. Webbia 44(2): 169–196. https://doi.org/10.1080/00837792.1990.10670474 [In Italian]

Follieri M, Magri D, Sadori L (1988) 250,000-year pollen record from Valle di Castiglione (Roma). Pollen et Spores 30: 329–356.

Ganeva A, Natcheva R (2003) Check-list of the bryophytes of Bulgaria with data on their distribution. I. Hepaticae and. Anthocerotae. Cryptogamie. Bryologie 24(3): 229–239.

Ganeva A, Natcheva R (2004) An overview of the Bulgarian bryophyte flora: Past, present and future. Phytologia Balcanica 10(1): 21–27.

Hedenäs L (2009) Relationships among arctic and non-arctic haplotypes of the moss species *Scorpidium cossonii* and *Scorpidium scorpioides* (Calliergonaceae). Plant Systematics and Evolution 277(3–4): 217–231. https://doi.org/10.1007/s00606-008-0131-y

Hedenäs L, Eldenäs P (2007) Cryptic speciation, habitat differentiation, and geography in *Hamatocaulis vernicosus* (Calliergonaceae, Bryophyta). Plant Systematics and Evolution 268(1–4): 131–145. https://doi.org/10.1007/s00606-007-0529-y

Hedenäs L, Eldenäs P (2008) Relationships in *Scorpidium* (Calliergonaceae, Bryophyta), especially between *S. cossonii* and *S. scorpioides*. Taxon 57: 121–130.

Hedenäs L, Collart F, Heras P, Infante M, Kooijman A, Kučera J (2022) Distributions and habitats of the two partly allopatric cryptic species of the vulnerable moss *Hamatocaulis vernicosus* (Bryophyta) in Europe. Botanical Journal of the Linnean Society 200(2): 233–254. https://doi.org/10.1093/botlinnean/boac011

Hodgetts N, Lockhart N (2020) Checklist and country status of European bryophytes –update 2020. Irish Wildlife Manuals, No. 123. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland.

Hodgetts N, Cálix M, Englefield E, Fettes N, García Criado M, Patin L, Nieto A, Bergamini A, Bisang I, Baisheva E, Campisi P, Cogoni A, Hallingbäck T, Konstantinova NA, Lochhart N, Sabovljevic M, Schnyder N, Schröck C, Sérgio C, Sim-Sim M, Vrba J, Ferreira C, Afonina OM, Blockeel TL, Blom HH, Caspar S, Gabriel R, Garcia C, Garilleti R, González Mancebo J, Goldberg I, Hedenäs L, Holyoak DT, et al. (2019) A miniature world in decline: European Red List of Mosses, Liverworts and Hornworts. Brussels, Belgium. https://doi.org/10.2305/IUCN.CH.2019.ERL.2.en

Hodgetts NG, Söderström L, Blockeel TL, Caspari S, Ignatov MS, Konstantinova NA, Lockhart N, Papp B, Schröck C, Sim-Sim M, Bell D, Bell NE, Blom HH, Bruggeman-Nannenga MA, Brugués M, Enroth J, Flatberg KI, Garilleti R, Hedenäs L, Holyoak DT, Hugonnot V, Kariyawasam I, Köckinger H, Kučera J, Lara F, Porley RD (2020) An annotated checklist of bryophytes of Europe, Macaronesia and Cyprus. Journal of Bryology 42(1): 1–116. https://doi.org/10.1080/03736687.2019.1694329

IUCN (2012a) IUCN Red List categories and criteria: Version 3.1. Second edition. IUCN Species Survival Commission, Gland, Switzerland and Cambridge, 32 pp.

IUCN (2012b) Guidelines for application of IUCN Red List criteria at regional and national levels. Version 4.0. IUCN Species Survival Commission, Gland.

IUCN (2014) Guidelines for using the IUCN Red List categories and criteria. Version 11. Prepared by the Standards and Petitions Subcommittee. IUCN ,Gland, Switzerland and Cambridge, UK.

IUCN (2022) Guidelines for using the IUCN Red List Categories and Criteria. Version 15.1. Prepared by the Standards and Petitions Committee. https://www.iucnredlist.org/documents/RedListGuidelines.pdf

Kophimai Y, Peintinger M, Werth S, Cornejo C, Scheidegger C, Bergamini A (2014) Ploidy level, genetic diversity, and differentiation in two closely related mosses, *Scorpidium cossonii* and *S. revolvens* (Calliergonaceae). Journal of Bryology 36(1): 33–43. https://doi.org/10.1179/1743282013Y.0000000078

Lattanzi E, Tondi G, Di Pietro R (1999) Segnalazioni floristiche italiane: 909. Informatore Botanico Italiano 30(1998): 64.

Lesica P, Allendorf FW (1995) When are peripheral populations valuable for conservation? Conservation Biology 9(4): 753–760. https://doi.org/10.1046/j.1523-1739.1995.09040753.x

Magri D (2008) Lineamenti della vegetazione tardoglaciale in Italia peninsulare e in Sicilia [Features of tardoglacial vegetation in peninsular Italy and Sicily]. In: Mussi M (Ed.) Il Tardiglaciale in Italia – Lavori in Corso. BAR International Series, vol. 1859, Archaeopress, Oxford, 1–8. [in Italian]

Mastracci M, Düll R (1991) Le raccolte delle escursioni del Congresso Internazionale di Briologia, L'Aquila 15–26. 7.1991. In: Mastracci M (Ed.) Atti del Congresso Internazionale di Briologia (L'Aquila, 15–26 luglio 1991): 93–124.

Moss D (2008) EUNIS Habitat Classification – A Guide for Users. Copenhagen: European Environment Agency.

Mucina L, Bültmann H, Dierßen K, Theurillat JP, Raus T, Čarni A, Šumberová K, Willner W, Dengler J, García RG, Chytrý M, Hájek M, Di Pietro R, Iakushenko D, Pallas J, Daniëls FJA, Bergmeier E, Guerra AS, Ermakov N, Valachovič M, Schaminée JHJ, Lysenko T, Didukh YP, Pignatti S, Rodwell JS, Capelo J, Weber HE, Solomeshch A, Dimopoulos P, Aguiar C, Hennekens SM, Tichý L (2016) Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen and algal communities. Applied Vegetation Science 19(S1): 3–264. https://doi.org/10.1111/avsc.12257

Natcheva R, Ganeva A, Spiridonov G (2006) Red List of the bryophytes in Bulgaria. Phytologia Balcanica 12(1): 55–62.

Orsomando E (1972) Nuova stazione di abete bianco (*Abies alba* Mill.) sui Monti della Laga nelle Marche. Archivio Bototanico Biogeografico ltaliano 48: 124–130.

Pedrotti F (1982) La végétation des Montes de la Laga. In: Pedrotti F (Ed.) Guide Itinérarie Excursion Internationale de Phytosociologie en Italie centrale (2–11 jullet 1982): 365–371.

Pedrotti F (1985) Segnalazioni floristiche italiane: 259–267. Informatore Botanico Italiano 15(2–3): 195–197.

Pedrotti F, Cortini Pedrotti C (1978) Segnalazione di *Vaccinium gaultherioides* Bigelow per l'Italia centrale. Giornale Botanico Italiano 112: 287–288.

Pignatti S, Guarino R, La Rosa M (2017–2019) Flora d'Italia, 2a Edizione. Edagricole - Edizioni Agricole di New Business Media, Bologna.

Privitera M, Puglisi M, Di Pietro R (2006) Su alcuni nuovi record per la brioflora dell'Abruzzo (Italia centrale). Informatore botanico Italiano 38 (2): 541–544.

Puglisi M, Privitera M (2018) New Moss Records for the Mediterranean Islands. Cryptogamie. Bryologie 39(2): 177–183. https://doi.org/10.7872/cryb/v39.iss2.2018.177

Puglisi M, Privitera M, Di Pietro R (2011) New records of arctic montane and alpine mosses from Central Italy. Cryptogamie. Bryologie 32(1): 75–81. https://doi.org/10.7872/cryb.v32.iss1.2011.075

Puglisi M, Campisi P, Aleffi M, Bonini I, Cogoni A, Dia MG, Miserere L, Privitera M, Tiburtini M, Poponessi S (2023) Red-list of Italian bryophytes. 1. Liverworts and hornworts. Plant Biosystems 157(4): 746–757. https://doi.org/10.1080/11263504.2023.2200791

Puglisi M, Campisi P, Aleffi M, Bacilliere G, Bonini I, Cogoni A, Dia MG, Miserere L, Privitera M, Tiburtini M, Poponessi S (2024) Red-list of Italian bryophytes. 2. Mosses. Plant Biosystems. https://doi.org/10.1080/11263504.2024.2386330

Rabenhorst L (1849–50) Vorläufiger botanischer Bericht über meine Reise durch die östlichen und südlichen Provinzen Italiens im Jahre 1847. Flora 1849, 25: 385–399, 26: 434–444; 1850, 20: 305–313, 21: 322–325, 22: 338–349, 23: 355–363, 24: 372–383, 25: 390–399.

Rivas-Martínez S, Penas A, Díaz TE (2004) Bioclimatic and biogeographic maps of Europe. University of León. https://www.globalbioclimatics.org/form/maps.htm

Rossi G, Gentili R (2006) Applicazione dei Criteri IUCN a popolazioni periferiche di specie artico-alpine in Appennino settentrionale. Lav. Soc. Ital. Biogeogr. (Biogeographia) 27: 307–326. https://doi.org/10.21426/B6110046

Schaminée JHJ, Chytrý M, Hennekens SM, Mucina L, Rodwell JS, Tichý L (2012) Development of Vegetation Syntaxa Crosswalks to EUNIS Habitat Classification and Related Data Sets. Report to the European Environment Agency. Alterra WUR, Wageningen.

Singh P, Ekrtová E, Holá E, Štechová T, Grill S, Hájek M (2021) Restoration of rare bryophytes in degraded rich fens: The effect of sod-and-moss removal. Journal for Nature Conservation 59: 125928. https://doi.org/10.1016/j.jnc.2020.125928

Thiers B (2022) [continuously updated] Index Herbariorum: A Global Directory of Public Herbaria and Associated Staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/science/ih/

Tomaselli M, Agostini N (1994) A comparative phytogeographic analysis of the summit flora of the Tuscan-Emilian Apennines and of the Apuan Alps (northern Apennines). Fitosociologia 26: 99–110.

Tomaselli M, Bernerdo L, Passalacqua N (2003) The vegetation of *Ranunculo-Nardion* in the Southern Apennines. Phyton 43(1): 39–57.

Tondi G (2000) La flora di altitudine dei Monti della Laga (Appennino centrale). Annali dei Musei Civici-Rovereto. Sezione Archeologia, Storia. Naturwissenschaften 14(suppl.): 177–190.

Tondi G, Plini P (1995) Prodromo della Flora dei Monti della Laga (Appennino centrale, versante laziale) [Contributo alla conoscenza del Parco Nazionale del Gran Sasso e Monti della Laga]. ACLI Anni Verdi, Roma, 204 pp.

Tondi G, Di Pietro R, Ballelli S, Minutillo F (2003) New contribution to the knowledge of the flora of the Laga Mountains (Central Apennines). Webbia 58(1): 57–76. https://doi.org/10.1080/00837792.2003.10670744

Zodda G (1910) Sulle epatiche dell'Italia meridionale e della Sicilia conservate negli erbari del R. Orto Botanico di Napoli. Bull. Orto Bot. Regia Univ. Napoli 2: 313–322.

Zodda G (1947) Sulla presenza di *Lycopodium complanatum* L. in Abruzzo. Nuovo Giornale Botanico ltaliano LIV: 792–793.

Appendix 1

List of the complete names of the syntaxa quoted in the text

Achilleo mucronulatae-Saxifragetum aizoidis Di Pietro, Conti et Vannicelli-Casoni 2001; *Armerio canescentis-Salicetum herbaceae* Biondi, Allegrezza, Ballelli & Taffetani 2000; *Betulo carpaticae-Alnetea viridis* Rejmánek ex Boeuf, Theurillat, Willner, Mucina et Simler in Boeuf et al. 2014; *Caricetum kitaibelianae-rupestris* Biondi, Allegrezza, Ballelli & Taffetani 2000; *Caricion bicoloris-atrofuscae* Nordhagen 1936 (= *Caricion atrofusco-saxatilis* Nordhagen 1943); *Caricion davallianae* Klika 1934; *Caricion intricatae* Quézel 1953; *Caricion viridulo-trinervis* Julve ex Hájek et Mucina in Theurillat et al. 2015; *Carpinion betuli* Issler 1931; *Cratoneurion commutati* Koch 1928; *Festucion frigidae* Rivas-Mart. et al. 2002; *Galio magellensis-Silenetum acaulis* Blasi, Di Pietro, Fortini, Catonica 2003; *Leontopodio nivalis-Elynetum myosuroidis* Feoli-Chiapella & Feoli 1976; *Narthecion scardici* Horvat ex Lakušić 1968; *Prenantho purpureae-Fagetum sylvaticae* Di Pietro 2007; *Saxifrago-Tomentypnion* Lapshina 2010; *Scheuchzerio palustris-Caricetea fuscae* Tx. 1937; *Sphagno warnstorfii-Tomentypnion nitentis* Dahl 1957.